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THE ORIGIN OF PETROLEUM IN THE LIGHT OF RECENT RESEARCH

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The story of the formation of crude petroleums and natural gas is not only an intriguing, scientific puzzle, or rather a series of scientific puzzles of general chemical and geological interest, but it is of the greatest practical importance to petroleum geologists. If we knew the entire story it would enable us to understand why large continental areas are entirely without accumulations of petroleum of commercial importance and why, in certain areas, perfectly good geological structures favorable to the accumulation of petroleum have been drilled and no petroleum or natural gas whatever has been found. A great deal of geological and chemical knowledge has been accumulated, particularly in recent years, and some of the questions in regard to the origin of petroleum and natural gas can now be definitely answered; other facts still await definite or plausible answers. Our knowledge of the subject to date represents a vast amount of investigation by a great many able chemists, geologists and others, and the general overall problem still includes many unsolved questions, the answer to which will require much more work and the best thought of the best minds.

I believe that our present knowledge enables us to draw certain conclusions which should be helpful to petroleum geologists and should be helpful to chemists and refiners in understanding the nature of crude petroleums with which they have to work. It is not too much to say that study of this problem now enables us to predict with fair assurance the nature of a crude petroleum which might be expected when drilling to various depths into oil-producing strata of different geological ages. If it is known beforehand at about what depth a particular producing sand is to be expected, we may be reasonably sure of the kind of crude we will find. There are some exceptions to this and the reasons for these exceptions are also significant and are part of the story.

The following diagram indicates approximately what the distribution of carbon is in the lithosphere (Fig. 1), which is as far as our knowledge goes. The relative proportions of carbon locked up in carbonate rocks, particularly limestones and dolomites, coal and petroleum, is roughly indicated. The carbon in oil shale was overlooked but should be a figure somewhat greater than that for oil. The source of the carbon dioxide before it was locked up in these carbonate rocks and, through animal and plant organisms, in oil shale, coal and petroleum is another story involving the source and nature of the earth's primitive atmosphere.

It is apparent that no figures for these quantities of carbon can be really accurate but their *relative* magnitude approximately, is as follows:

Carbon in carbonate rocks	2,310,000
Carbon as CO_2 and CO_3 in sea water	2,180
Carbon in coal	1,200
Carbon as CO_2 in air	68.
Carbon in petroleum	4.2

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The latter figure is based upon an estimate of the world's *known* recoverable reserves made for the Government during the last war. The actual figure may be twice or three times this figure (or about 150 billion barrels).

FUNDAMENTAL GEOLOGICAL CONDITIONS

Although the aspects of the origin of petroleum and natural gas which we are discussing here are mainly chemical, we must first consider a little geological history and the fundamental conditions which geology imposes upon us in considering the problem. Thus geology gives us the framework as to time, temperatures and pressures, the original environment and present environment, and probable nature of the original source material of petroleum, within which set of conditions we must work out the story of petroleum formation.

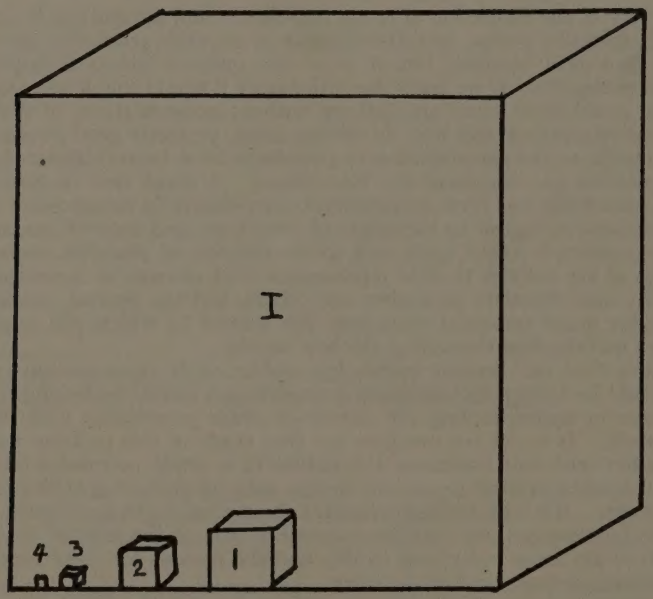


FIG. 1. Distribution of carbon, according to J. G. Bennett.
I. Carbonate rocks.
1. CO_2 in Sea water. 2. Coal. 3. CO_2 in atmosphere. 4. Petroleum.

Most of the theories proposed by chemists for the origin of petroleum and natural gas have neglected to take into account these fundamental conditions which have been by now firmly established by petroleum geologists, and most of them must be rejected because they do violence to and cannot be reconciled with these fundamental conditions. As stated by Beeby Thompson (2), "In seeking the origin of petroleum one must not introduce extraordinary theories for its occasional occurrence amongst unusual surroundings, but consider only such views as will account for its extensive production and wide distribution by common processes of nature."

At this point we may refer to a simplified geological column, Fig. 2, which shows the order in which the sedimentary rocks of the different periods were laid down. By the study of radioactive minerals in intrusive rocks, such as pegmatites,

	Geological Scale	Age in Millions of Years	Oil Fields
Quaternary			
Tertiary	Pleistocene		Caucasus, Iran, Irak
	Pliocene		California
	Miocene	13 ± 1	Gulf Coast Salt Domes
	Oligocene	18 ± 1.5	Venezuela, Colombia
	Eocene	34 ± 2	Trinidad
	Poleocene	57 ± 1.5	Texas, East Texas
Mesozoic	Cretaceous		Rodessa field
		85	Woodbine sand
	Jurassic		Mexico
	Triassic	165 Palisades Uplift	
		180 Watchung Mts.	
	Permian		West Texas and Eastern New Mexico
		230 ± 15	
	Carboniferous		U. S. Appalachian Michigan Illinois
Paleozoic	Devonian	300	Midcontinent
	Silurian	Adirondacks	
		370 ± 30	Ohio–Indiana
	Ordovician		Wilcox Sands of Midcontinent
Eozoic	Cambrian	400	
		535 ± 25	
	Kewenowan		

Fig. 2. Time or geologic age based upon a study by W. D. Urry and others from the study of radioactive minerals in pegmatite intrusions.

we now know fairly accurately the age of these sedimentaries in terms of millions of years. Beginning with the top of the Cambrian series with an age of about four hundred million years, we come down to the most recent periods containing petroleum, to the Pliocene, geologically very recent with an age of about ten to twelve million years. This simplified geological column is drawn to a scale proportional to time and bears no relation to the thickness of the strata in the various series. Approximately two-thirds of our current oil production and known reserves occur in the Cretaceous and above. The reason for this is that by this time the continental areas had become much more extensive and the erosion from these continental areas resulted in the deposition of thick marine sediments, and where this erosion and deposition took place relatively rapidly in lagoons or large basin areas or, in some cases, along shore lines, we then have the first basic requirement for the ultimate production of petroleum and natural gas.

There are three general types of organic matter found in large quantities practically throughout this geological column; they are, coal, the so-called kerogen in oil shales, and petroleum and natural gas. Coals are generally believed to have been derived from quite different source material than kerogen, petroleum and gas, and evidently were fresh water or marsh deposits derived from lush vegetation, and cellulose, lignins and resins constitute the principal source material. The original organic source material of kerogen, petroleum and natural gas, was laid down in *marine* and in fresh water sediments.

The original organic source material which resulted in the formation of kerogen and of petroleum and natural gas is still uncertain and may have varied somewhat. Shales, in general, are deep water deposits whereas sandstones and limestones are laid down at relatively shallow depths. It is a striking fact that the so-called kerogen of oil shales has persisted, apparently unchanged, from geologic times as remote in certain cases as the upper part of the Cambrian series, or about four hundred million years. In other words, there is no evidence that the temperatures and other conditions normally prevailing in any of these old strata has ever decomposed kerogen or converted it to oil. Most oil shales contain no petroleum whatever, and others only very minor proportions. Oil shales containing kerogen may be as much as four hundred million years old, as the New Brunswick oil shale, (9) or the extensive black shales of New York, Ohio and Michigan, which are Devonian. Yet petroleums may be as recent as the Pliocene as, for example, those from the Midway fields of California. The original organic source material of both oil shale and petroleum was at least associated with, and probably derived from, at least in part, green algae, since Treibs (28) has found chlorophyll porphyrine in all oil shales examined by him and in all petroleums containing asphalt or, in other words, in all petroleums not purified by selective adsorption during migration. This discovery of chlorophyll porphyrins is undoubtedly the most important single discovery bearing upon the question of petroleum origin. It definitely connects up both oil shales and petroleum with green algae and proves that both have never been at any time in their history subjected to high temperatures and, in agreement with other evidence, shows that the original organic source material was deposited sufficiently rapidly to seal in the organic debris under anaerobic conditions. Certain oil shales studied by Treibs contain half as much chlorophyll porphyrin material as can be derived from dried green leaves. All sorts of marine animal and vegetable life probably contributed to the organic debris deposited in the original ocean sediments. Several years ago, the American Petroleum Institute conducted extensive investigations under the direction of Parker D. Trask into contemporary sediments currently being deposited in various parts of the oceans. These investigations found no petroleum in these sediments and do not throw much light on the nature of the organic material contained in them. The kerogen of oil shale is a highly complex material, evidently in a highly polymerized condition as indicated by its insolubility in all organic solvents at ordinary temperatures.

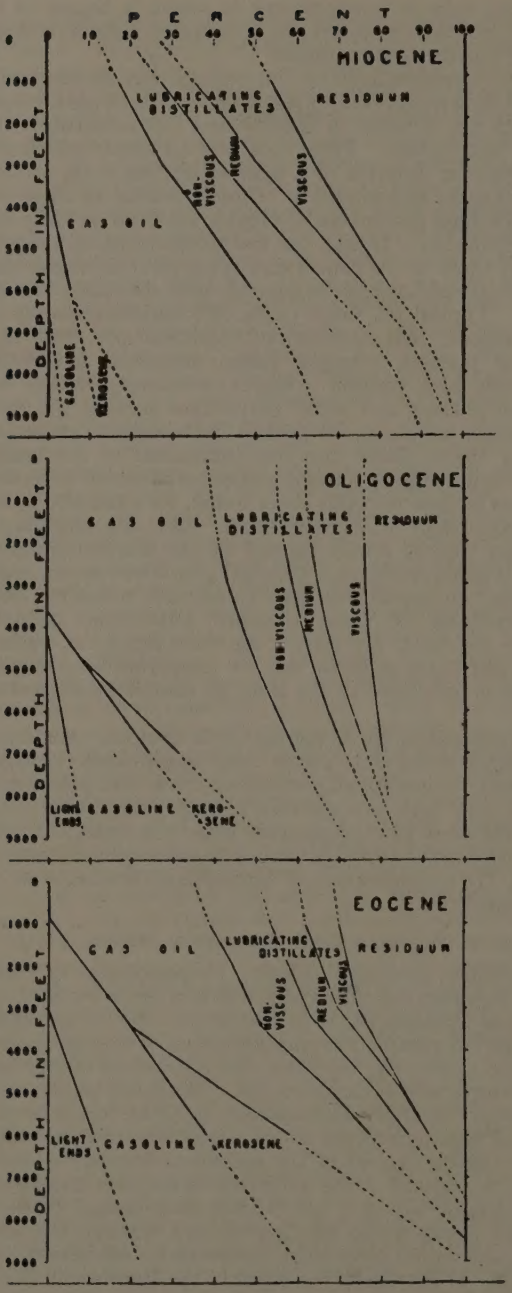
It can be extracted by solvents only at temperatures at which it begins to be decomposed. Fatty oils found in very recent deposits of decaying algae have been found to be already in a partly polymerized condition.

As might be expected from considerations of the original environment and original organic source material of kerogen, oil and gas, and coal, there are deposits of fossil organic material which are difficult to classify and fall in between the three typical major materials just named. Thus there are oil shales which are very rich in organic material yielding upwards of a hundred gallons of oil per ton and include the type of shales known as torbanites. Closely related to these are the cannel coals which contain a high percentage of organic material yielding oils and paraffins by destructive distillation. In fact, the low temperature destructive distillation of coals, particularly those of the cannel coal type, yield distillates rich in paraffins and unsaturated hydrocarbons and, in general, such distillates are not very different from shale oil. Typical oil shale yields oil consisting mainly of paraffins, naphthenic hydrocarbons, and unsaturated hydrocarbons, but also relatively large proportions of phenols, nitrogen bases, ammonia and sulfur derivatives. Typical petroleums also contain complex substances which are decomposed on heating to give phenols and sulfur derivatives such as the mercaptans, thio-ethers and thiophenes which are not present in the original crude but are decomposition products of thermo-labile complex substances in the crude. Similarly, crude petroleums contain complex nitrogenous material which is decomposed at moderate temperatures to give nitrogen bases found, for example, in the kerosene distillates in small proportions of all petroleums. Also, the naphthenic acids found in the distillates are almost wholly formed by the decomposition of more complex material in the original crude oil. Cracked gasolines contain small proportions of phenols and these have sometimes been industrially recovered from cracked gasolines. The proportions of these so-called impurities, phenols, naphthenic acids, nitrogen bases and sulfur derivatives, are much smaller in cracked gasoline than in shale oils and distillates made by the low temperature carbonization of coal, but their presence is indicative of the same or similar substances in the crude materials.

The existence in crude petroleums of these thermo-labile complex substances which yield mercaptans and other sulfur derivatives, naphthenic acids, nitrogen bases, together with the presence of chlorophyll porphyrins show that petroleums have never been subjected to very high temperatues at any time during their history. (6) This chemical evidence of low temperature history is consistent with the evidence of low temperatures derived from the actual measurement of bottom-hole temperatures in oil fields, the consideration of temperature gradients in oil fields and general geological considerations.

LACK OF KNOWLEDGE OF PETROLEUM IN TRANSITION STAGES

Referring again to the simplified geological column, no petroleums or other bituminous material has been investigated chemically which is more recent than the Midway-California oils from Pliocene sands in California. In other words, there is at present a complete gap as regards the transformation of organic matter in contemporary sediments into petroleum, between the Pliocene of about ten million years ago and the sediments now being deposited. It should be expected that a satisfactory chemical history of this transformation could be found by the examination of organic material in intermediate states. Such material certainly exists and awaits study. The organic matter in the sediments is solid, or semi-solid, and has to be in order to be retained in the sediments as they are laid down. Such material in intermediate stages, before it has become fluid enough to flow, migrate and collect in so-called pools, would be disseminated through the geologically recent sands or shale, and would have to be recovered by extraction. A few years ago, Donald C. Barton, (1) Petroleum Geologist of the Humble Oil Com-



pany, as a result of a study of Gulf Coast petroleums and the relations between their composition and geological age and depth, arrived at this conclusion merely by extrapolation when the data was plotted geographically.

The heavy, black, tarry oils in geologically recent tar sands should repay investigation as possibly being petroleum in very early transition stages of formation. At some early stages geologically recent natural bitumens might be expected to show a much higher content in organic acids than typical petroleums. The observation of Pyhala (18) that in the case of two Russian oils, the distillates showed 11 to 12 times as much naphthenic acids as the original crudes suggests that determination of saponification numbers on crude petroleums, particularly heavy naphthenic, geologically recent oils and tars would probably show much higher saponification numbers in the recent material. The organic nitrogen content would also be of interest. There are reasons, mentioned later, for expecting that such transition material would show substantial olefinic unsaturation, perhaps unsaturated fatty acids or their polymers.

Barton's studies are shown in the accompanying graphs, Figures 3, 4 and 5. It has long been recognized that, in general, the light crudes containing much

FIGS. 3–5. Composition of Gulf Coast oils, plotted graphically according to D. C. Barton.

gasoline and generally paraffinic in type, are geologically much older than the heavy, asphaltic crudes containing little or no gasoline. Barton's study of the Gulf Coast oil was the first systematic investigation bearing on this point. Subsequent investigations in the Gulf Coast area have shown that the relations are not so simple as indicated by these graphs, but the general results or the average of the results are as shown by Barton. In other areas, notably in Wyoming and California, the relations found by Barton do not hold very well, but many of the apparent exceptions are due to changes in the crude oil by selective adsorption in migration.

TEMPERATURE IN OIL FORMATION

The subject of temperature as a factor in petroleum formation has been very frequently discussed since it was first suggested by Warren and Storer in 1863 and later in 1888 by Engler, (10) that petroleums resulted from a destructive distillation of fatty oils derived from fish or other marine life, but it has become increasingly difficult to reconcile such a process with the chemical and geological evidences of low temperature history.

We now know a good deal concerning the individual hydrocarbons present in petroleums, particularly in the gasoline and lighter kerosene fractions. This information, which has largely been a result of about twenty years of investigation by the U. S. Bureau of Standards (19) as a research project financed by the American Petroleum Institute, is summarized in the following tables. (22) Consideration of the composition of these gasolines permits the conclusion to be drawn that they are not equilibrium mixtures corresponding in composition to any particular thermal condition.

TABLE III

HYDROCARBON TYPES IN STRAIGHT-RUN GASOLINES

CRUDE OIL	END POINT (° C.)	PER CENT BY WEIGHT OF		
		Aromatics	Naphthenes	Paraffins
Oklahoma City, Okla.	177	10	29	61
Tonkawa, Okla.	150	9	35	56
" "	210	12	37	49
Davenport, Okla.	150	8	28	64
" "	210	11	28	61
East Texas	159	6	42	52
Mexia, Texas	150	22	21	57
" "	210	18	21	61
Rodessa, La.	160	10	20	70
Santa Fe Spr., Cal.	151	10	50	40
Kettleman Hills, Cal.	151	8	45	47
Signal Hill, Cal.	153	6	52	42
Huntington Beach, Cal.	155	7	49	44
" " "	210	11	54	35
Turner Valley, Canada	150	11	38	31
" " "	200	15	35	50

TABLE IV

CHEMICAL COMPOSITION OF LIGHT PARAFFIN-NAPHTHENE FRACTION, 40° TO 102° C. OF U. S. STRAIGHT-RUN GASOLINES

GASOLINE	PERCENTAGE BY VOL.			
	Normal Paraffins	Isoparaffins	Cyclo-pentanes	Cyclo-hexanes
Ponca, Okla.	35.7	20.5	23.4	20.4
East Texas	24.7	27.3	26.0	22.0
Bradford, Pa.	34.4	32.2	13.4	20.0
Greendale-Kawkawlin, Mich.	63.1	13.2	8.0	15.7
Winkler, Texas	9.5	61.6	8.4	20.5
Midway, Cal.	10.0	21.5	41.0	27.5
Conroe, Texas	18.2	20.3	17.3	44.2

The aromatic content of the gasoline, distilled up to 180° C. from the same crudes is as follows:

TABLE V

CONTENT OF AROMATICS IN U. S. STRAIGHT-RUN GASOLINES (E. P. 180° C)*

Gasoline	Aromatic Content (% by weight)
Ponca, Okla.	9.8
East Texas	10.4
Bradford, Pa.	8.3
Greendale-Kawkawlin, Mich.	7.2
Winkler, Texas	4.9
Midway, Cal.	8.0
Conroe, Texas	27.6

Dr. Frederick Rossini, under whose direction much of this analytical study was made, and in my opinion the analytical results are beyond question, has recently pointed out that the relative proportions of certain *selected* groups of constituents correspond approximately to the proportions required by thermal equilibrium at about 400° C. or 752° F. (20). Dr. Rossini stated that this would have to be taken into account in any theory of the formation of petroleum. However, the geological history and other chemical evidence must be taken into account. Also, it should be pointed out that all of the analyses are taken into account, it is apparent that these gasolines do not represent thermal equilibrium mixtures. At temperatures below about 200° C. thermo drynamic considerations teach that the iso-paraffins are more stable than the normal paraffins. Yet the gasoline fraction from Michigan crude contains 63.1 per cent of normal paraffins and 13.2 per cent of iso-paraffins. In contrast to this, the gasoline from Winkler crude contains 95. per cent normal paraffins and 61.6 per cent of iso-paraffins. The gasoline from Yates, Texas, crude is reported to contain no normal paraffins. The Michigan crude is geologically much older than the Winkler crude and both are obtained from wells whose bottom-hole temperatures are below 100° F.

The above tables also show the greatest variation in the relative proportions of cyclopentanes and cyclohexanes and there is no simple relation between the proportions of cyclohexanes and aromatic hydrocarbons. There is no indication that the aromatic hydrocarbons have been derived from cyclohexanes by catalytic dehydrogenation. It will be noted that the gasoline from Conroe crude, containing 27.6 per cent of aromatics is entirely out of line with all the others studied and

* Possible deviations from the above figures ±0.2 to 0.5.

is quite unlike gasolines from other crudes of similar geologic age, depth of producing strata, and observed bottom-hole temperatures.

If petroleums were produced from the original organic source material by thermal action *alone*, then oils of similar age and similar temperature history should have the same composition, but this is not even approximately true. The following table gives the approximate age, observed bottom-hole temperatures and depth of the producing formation for the seven crudes investigated by the Bureau of Standards. The highest bottom-hole temperature is that of the Conroe field where the temperature at 4,900 foot depth is 172° F. In the Permian basin of West Texas, the temperature is only 126°F. at 5,900 feet below sea level. In the East Texas field, the producing formation is the Woodbine sand of the Cretaceous producing from a depth of 3,300 feet below sea level and a bottom-hole temperature of about 146° F. Oils of the Permian basin of West Texas are much older than either the Conroe or East Texas oils.

The temperature history of petroleum begins with the temperature at which the original source sediments are laid down in the ocean, probably an average of 60–70° F. As the despoits build up in thickness they serve as an insulating blanket and in the course of time the temperature slowly rises as the thickness of the strata or depth increases. The temperature gradients in the various oil fields varies from about 50 feet to 100 feet for each increase in temperature of one degree Fahrenheit. (13) The present observed bottom-hole temperatures probably represent the maximum temperature for the entire geologic history of a particular producing formation, except in old regions which have been highly eroded and where the producing sands are now near the surface. McCoy and Keyte (16) state that "most of the known oil fields surely were formed at temperatures lower than 140° F." Some of our most prolific fields yield oil from formations whose bottom-hole temperatures do not exceed 100° F. At Oklahoma City, a temperature of 100° F. is found at 4,100 feet.

Barton states: "The geologic history of the Gulf Coast is relatively simple. It is quite impossible that the Gulf Coast crude oils which are now being produced have been subjected to temperature as (high as) 100° C. Some of the crude oil from the deeper sands may have been subjected to temperatures as high, but not much higher than 70° C. Much of the crude oil cannot have been subjected to temperatures much higher than 50° C.—the normal average crude oil is indigenous to the formation in which it is found and has not migrated up from greater depth."

Since the straight run gasolines that have been most carefully analyzed are those noted in the above tables, the following data are given for these crudes:

TABLE VI

GEOLOGICAL AND FIELD DATA FOR SELECTED CRUDES

Field, Source of Crude	Producing Sand	Series	Depth, Average Feet	Bottom Hole Temp. °F.	Estimated Age in Million Years*
Ponca, Okla.	Wilcox	Middle Ordovician	3,872	139°	360–380
East Texas	Woodbine	Cretaceous	3,300	146°	60–80
Bradford, Pa.	Bradford	Devonian (Chemung)	2,000	72°	300
Greendale, Mich.	?	Middle Devonian	5,300	96°	300
Winkler, Texas	Big Lime	Permian	3,000	85°	200–230
Midway, Cal.		Pliocene	2,050	115°	10–13
Conroe, Texas	Cockfield	Eocene	4,900	172°	40–50

* Based upon estimates by W. D. Urry and others from the study of radioactive minerals pegmatite intrusions.

CATALYTIC ACTION OF ACTIVE SURFACE MINERALS

The low temperature history of petroleums must be considered as firmly established by the field observations and the geological and chemical evidence.

However, we must consider the evidence that petroleums do change. Heavy, asphaltic, naphthenic oils change to lighter, more paraffinic oils and contain more light constituents, such as gasoline, as these changes proceed. We must also consider the great complexity of petroleums and the very large number of hydrocarbons present, beginning with the gases, methane, ethane and propane, et cetera, up to and including mixtures of high boiling hydrocarbons which are beyond our power of analysis and identification. It has been calculated, (23) by employing the velocity constants for cracking, that at 212° F. the higher paraffins have a stability greater than the element potassium, and according to these calculations, the paraffins would remain substantially unchanged if maintained at 300° F. throughout geologic time from the middle Ordovician to the present. These facts can be reconciled, however, if we suppose that *clays and possibly other minerals common in the strata in contact with petroleums have a catalytic action, at the observed relatively low temperatures, on the crude oil and on the heavy bituminous material formed in the early stages of oil formation.* That clays and certain other minerals may have such a catalytic effect is indicated not only by the evidence just noted, but also by the fact that certain natural clays and special silica-alumina catalysts and silica-magnesia catalysts are industrially employed in catalytic processes at relatively high temperatures, 850–950° F. and that at low temperatures many of these clays and minerals show very high catalytic activity with respect to the polymerization of unsaturated hydrocarbons. Clays such as Fuller's earth are capable of polymerizing iso-butene at temperatures as low as —100° C. and, in general, the lower the temperature the higher the molecular weight of the polymers formed. 2-Butene is 85 per cent polymerized by Fuller's earth on standing four months at room temperature. This property of polymerizing unsaturated hydrocarbons is not limited to Fuller's earth but, as pointed out in an earlier paper by the writer, is a general property common to all clays and rocks containing clay. Very reactive hydrocarbons such as trimethyl ethylene, isobutene and pinene are polymerized at room temperature with evolution of heat by clays, not of the Fuller's earth type, bentonite, bauxite, sandstones and green-sand, although the activity of silica gel and pure kaolin is very slow.

The specimens of sedimentary rocks from Oklahoma which were tested for polymerizing activity are shown in the following table: (6)

POLYMERIZING EFFECT OF OKLAHOMA SEDIMENTARY ROCKS AND SOME MINERALS ON TURPENTINE

Mineral	*Per Cent Polymer*
Fuller's earth of Georgia	75
Sylvan shale	76
Red-bed clay	65
Tertiary clays	68
Greensand, New Jersey	72
Greensand, Texas	70
Serpentine, Easton, Pa.	60
Gray Persian sandstone	56
Stanley shale	57
Regan sandstone	50
Calvin sandstone	46
Simpson sandstone	34
Permian sandstone	30
Bentonite	34
Bauxite, Georgia	58
Silica gel	23
Kaolin	12
"Glaucosil" (acid leached greensand)	45

Mineral	*Per Cent Polymer*
Prehnite (zeolite)	None
Stilbite (zeolite)	None
Talc	None
Infusorial earth	None
Powdered pumice	None
Ferric oxide, pure	None
Aluminum oxide, pure	None

It will be noted in the above table that the six typical sandstones tested show a catalytic activity as indicated by polymerization averaging better than half the catalytic activity of typical Fuller's earth and that three Oklahoma clays showed activity very nearly as high as typical Fuller's earth. Even bauxite, which can have only a very small percentage of clay as an impurity, shows about two-thirds the plymerizing activity of Fuller's earth. It is indicated by these results that catalytic activity is not limited to acid clays, but is due to active surfaces which strongly adsorb the hydrocarbons.

At elevated temperatures different active surface materials show different results in catalytic cracking and other reactions. Thus, in catalytic cracking, the character of the gasoline obtained using a silica-alumina catalyst is different from the gasoline produced by a silica-magnesia catalyst, both at the same operating temperature. The silica-alumina catalyst yields more butens and low boiling material and has a somewhat higher octane number. In a study of the catalytic action of Fuller's earth and other catalysts on propylene it was found (12a) that at 350° C., or well below ordinary cracking temperatures, the product consisted of both isoparaffins and olefins, including many isomeric C_5, C_6, C_7, C_8 and C_9 hydrocarbons (29a). The gasoline thus produced had an octane number of 91. Synthetic aluminum silicate had approximately the same catalytic activity as the best activated Fuller's earth, and a catalyst made up of one per cent alumina on silica was twenty times as active as the best activated Fuller's earth.

These results show that paraffins are formed from olefins, that isomerization and splitting of the hydrocarbon molecules takes place very rapidly at temperatures substantially below cracking temperatures, in fact, high temperatures alone do not produce the same results noted in this catalytic conversion of propylene. Here we note much the same so-called "hydrocarbon dispersion" that is found in the composition of typical petroleums. This action of Fuller's earth and other active surface catalysts *proves* that many of the changes with which we are concerned in accounting for the complexity of petroleums do take place rapidly in the presence of such catalysts at temperatures at which the hydrocarbons are relatively stable, and that the reactions are in some respects different in kind from those resulting from the action of heat alone. The formation of some of the products in the resulting mixture can only be explained in the same way that the numerous products of the alkylation of isoparaffins by olefins are explained.

It is true that the complicated reactions which take place in low temperature alkylation processes occur through the action of reagents such as concentrated sulfuric acid, hydrofluoric acid, and aluminium chloride. Such processes include isomerization, the splitting of hydrocarbons and the synthesis of new ones, molecular rearrangements and so-called hydro polymerization. The mixture of hydrocarbons which results contains no olefins at all and when using isobutane and butenes the mixture contains not only the expected C_8 hydrocarbons, but also pentanes, hexanes, heptanes, nonanes and small proportions of heavier hydrocarbons. These reactions take place at low temperatures, refrigeration being required.

It is now generally accepted that all of these results are best explained by the formation of carbonium ions. The low temperature formation of the great number of hydrocarbons found in petroleum through the action of active surface minerals must have a similar mechanism.

Further evidence that the catalytic active-surface minerals play an important role in the formation of petroleum is found in the nature of the hydrocarbon constituents of typical petroleums. The fact that straight-run gasolines and kerosense contain no unsaturated or olefinic hydrocarbons is a strong indication of this and also the complexity of such oils or, in other words, the very large number of hydrocarbons, isomeric paraffins, naphthenes and aromatic hydrocarbons, has no other plausible explanation. The great number of hydrocarbons present in petroleums was one of the primary considerations of the old destruction distillation theory of Warren and Storer and of Engler, but the relatively high temperatures postulated by Engler, and recently by Rossini, are clearly beyond consideration.

The extremely great differences in the composition of petroleums and the wide variations in the composition of gasoline fractions have been noted and are shown by the above tables. Some differences in petroleums could be expected as a result in differences in composition or types of organic material which constitute the original source material but such differences in source material could still not possibly account for the great number of hydrocarnons which are evidently present in all petroleums. Some recent investigators have called attention to the fact that paraffins are found in nature in many plants, being formed by bio-chemical processes in the living plants. Some unsaponifiable hydrocarbon oil has been found in material extracted from decaying algae. However, it should be pointed out that when paraffins occur in nature, only one or two paraffins are formed and at most, not more than four in any one occurrence, and practically all of them are normal paraffins having an odd number of carbon atoms. They were apparently formed by loss of CO_2 from fatty acids which are found associated with these paraffins. Isomeric paraffins, naphthenes, or aromatic hydrocarbons, have never been found in such cases. In the decay of organic matter containing fatty oils, the hydrolysis to free fatty acids, the formation of insoluble soaps, loss of CO_2 and polymerization has been observed and probably takes place very early in the sequence of changes which form petroleum. But the formation of anything other than a very small number of normal paraffins by any biochemical process, including bacterial fermentation, has never been observed.

Consideration of all the above mentioned facts, and particularly the complexity of petroleum composition, leads directly to the conclusion that petroleum origin involves two general processes, (1) conversion of the organic source material into heavy, bituminous material approaching a hydrocarbon mixture in overall composition and, (2) what might be termed the "chemical dispersion" of this essential hydrocarbon material into the great series of paraffins and isomeric paraffins from methane to the solid waxes and also naphthenes and aromatic hydrocarbons. The very heavy viscous oils, often quite free from the lighter hydrocarbons such as gasoline, probably represent petroleum in a very early transition stage. There are many such tarry oils in the so-called tar sands as, for example, the very heavy asphaltic oil found in the upper sands of the Maracaibo basin.

Barton arrived at a similar conclusion in his study of Gulf Coast oils and their geology. "Evolution of crude oil from an original oil, perhaps something like the heaviest end of the residuum of the present Miocene Gulf Coast crude oils,—. The tentative deduction follows that the ancestral crude oil of the Gulf Coast crude oils was a heavy oil which, under the U. S. Bureau of Mines' method of analysis, would consist of residuum. Oils of that type should be too thick and viscous to move except through open channels. They may never be found in appreciable accumulations and may have to be sought as droplets scattered through the source formation."

In considering this suggestion of the role of the catalytic action of active surface minerals, we may summarize the limitations which appear to be imposed by the geologic history, physical conditions, and possible differences in environment which

have to be considered in any attempt to account for the differences in type and composition of petroleums:

1. Maximum temperatures varying from about 100° F. to 250° F.
2. Maximum pressures varying from possibly as low as about 1,500 pounds per square inch to about 6,000 pounds per square inch.
3. Time since deposition of original source sediments varying from about 10 to 350 million years (to middle Ordovician).
4. Contact with clays and sands of varying catalytic effects.
5. Unknown differences in type and chemical composition of original source material.
6. Selective adsorption during migration.

Some of the above named factors have already been commented upon. High pressures have often been assumed to have been a factor in the formation of petroleums. It is very doubtful, however, if pressures have been a factor of any importance. As indicated by observed bottom-hole pressures, these pressures vary from about 1,500 pounds, or even less, per square inch to the higher pressures found in deep wells in the range from about 3,000 to 6,000 pounds per squear inch. The observed pressures are seldom as great as the calculated hydrostatic head corresponding to the depth. Theoretically, the effect of high pressures, if any changes are effected by such pressure, should be to produce heavy oils with increasing depth and increasing pressure, which is just contrary to the facts generally observed. Such pressures as those just mentioned are hardly enough to influence chemical changes in the oi. mixture. Thus it is frequently assumed that pressures would bring about polymerization of any unsaturated hydrocarbons originally present. As against this it may be pointed out that Conant (7) and Peterson found that high pressures up to 15,000 atmospheres did not cause the polymerization of such very reactive, unsaturated hydrocarbons as isoprene and butadiene unless such material had previously been subjected to oxidation with the formation of peroxides which in themselves are well known polymerizing catalysts. They concluded that such high pressures, which are many times greater than those encountered in oil fields, cannot cause polymerization of even such very reactive dienes.

Changes in petroleums by selectife adsorption during migration are well known and need not be reviewed here.

If the catalytic action of active surface minerals, such as clays, has been a factor in producing the chemical changes noted by Barton in the Gulf Coast fields as mentioned above, then it might be expected that oils found in reservoir rocks, such as limestones, which have no catalytic action on hydrocarbons might be found to be out of line or inconsistent with the regularities noted by Barton. Once petroleum has migrated into a limestone reservoir rock it should undergo little or no further chemical change. An oil might even have been subjected to such catalytic action and have been converted into a relatively light crude before migrating into a limestone reservoir. Actually we do find many examples of very heavy oils containing little or no light constituents, such as gasoline, occurring in limestone reservoirs even though we would expect from their geologic age and depth that they would be much lighter and more paraffinic. Such oils are the very heavy, asphaltic crudes in Mexico, for example, the Panuco crude which is found in a Cretaceous limestone. A research committee of the Tulsa Geolgoical Society, including H. M. Smith of the United States Bureau of Mines, in a study of Mid-Continent oils (25) has shown that the Arbuckle limestone in southeastern Kansas contains a heavy, asphaltic oil containing none of the lighter fractions, and this is in great contrast to the lighter typical Mid-Continent crudes from much younger formations. The crude oil from the Trenton limetsone of the Lima-Indiana field is much heavier, more naphthenic and contains much less gasoline than the geologically more recent oil of the Bradford sand of Pennsylvania.

Differences in the catalytic activity of different formations of minerals in contact with crude oil may also account for the very puzzling fact that crude oils considerably different in composition are sometimes found separated vertically by only one or two hundred feet without any unconformity between the two producing formations. In such cases, the two oils must be of substantially the same geologic age and must have been subjected to substantially the same temperatures and pressures throughout their history. Smith and his associates suggested that such differences in crude composition may have been due to differences in the original environment of the source material or differences in the chemical composition of the original source material. There seems to be no tangible evidence for such assumed original differences but the observed facts may very plausibly be due to differences in the catalytic activity of the strata with which the oil has been in contact.

In the much folded, faulted and metamorphosed Rocky Mountain area the regularities in oil composition shown in the Gulf Coast fields is not shown. Dobbin (8) states that the quality of the oils in the Rocky Mountain area bear no demonstrable relation to the dynamic metamorphism which the region has under gone and notes, "It is evident, therefore, that in addition to metamorphism, there are other factors responsible for the quality of the oil, such as differences in origin—and *natural processes of refining or filtration.*"

FORMATION OF AROMATIC HYDROCARBONS

The apparently universal occurrence of aromatic hydrocarbons in petroleums, isolated and identified in straight-run gasolines, presents special difficulties. The proportions of aromatic hydrocarbons in various gasolines is given in the foregoing tables. In a few gasolines, such as that from Conroe, Texas, and certain of the Borneo crudes, the per cent of aromatics is very large. No type of abundant and widely-occurring possible source material contains aromatic groups sufficient to account for the presence of the aromatic hydrocarbons by any processes of simple degradation. Lignin and humic acids are the only natural materials occurring in abundance in nature which contain the benzene nucleus in its complex structure but they are almost certainly absent from the organic matter in marine deposits. They probably contribute to the formation of coal but not petroleum. The formation of aromatic hydrocarbons from paraffins has been treated from the thermodynamic standpoint by A. W. Francis (11) who states that temperatures in the range 550–900° C. are required, assuming the splitting off of hydrogen. According to Francis, the reactions possible below 550° C. are different in kind, so that at the lower temperatures the formation of aromatics from paraffins could not be expected even during geologic time. Experimental work bears out Francis' conclusions very well, so far as paraffins are concerned, although his temperature of 550° C. may be about 50° C. too high. The conclusions of Francis are very well confirmed by Taylor and Turkevich. (27)

There is a very extensive literature on catalytic dehydrogenation and the dehydrogenation of cyclohexane and its derivatives to benzene and its derivaties is a reversible process. The lower temperatures, in the presence of hydrogen, favor the conversion of benzenes to cyclohexanes, this reaction proceeding well experimentally at temperatures as low as 80°–100° C. with active catalysts. The dehydrogenation of cyclohexene to benzene in the presence of catalysts becomes noticeable experimentally at 170° C. Perhaps more significant is the fact that cyclohexene in the presence of certain catalysts undergoes hydrogen disproportionation being rapidly converted to benzene and cyclehexane, and pinenes are converted by Fuller's earth to cymene and para menthane, probably through the intermediate formation of terpinene, with evolution of considerable heat. The action of clays in causing such disproportionation reactions has also been mentioned by A. V. Frost, (12) in Russia, who also has suggested recently that clays have a role in

petroleum formation. According to Herington and Rideal, (14) the formation of aromatics from paraffins in the presence of a chromium oxide on alumina catalyst at 475° C., proceeds through the formation of a mono-olefin. Nenitzescu, (17) who also urges the study of geologically recent bituminous deposits as possible intermediates in petroleum formation, concludes that aromatic hydrocarbons are formed "at some low temperature" by an unknown process.

OTHER RECENT THEORIES

Brief mention should be made of recent researches seeking to explain pteroleum origin by bacterial action and by the effect of alpha radiation from radioactive minerals upon methane or upon the original organic source material of petroleum.

With respect to bacterial action, it is well known that methane is formed by bacterial action on cellulose. However, the formation of hydrocarbons, other than methane, in this way has never been observed and this appears to be a specific bacterial degradation of cellulose. Methane in relatively small amounts is frequently observed in coal deposits, but in such cases is not accompanied by the series of methane homologs found together with methane in natural gas. These two occurrences of methane appear to be entirely unrelated.

Loss of CO_2 from fatty acids has been observed in anaerobic fermentations and the destruction of petroleum oils by bacterial action (30) under *aerobic* conditions, probably by oxidation, has been reported by several observers.

NATURAL GAS AND THE RADIOACTIVITY THEORY OF PETROLEUM ORIGIN

S. C. Lind (15) has shown that the action of alpha radiation from radioactive material on gaseous hydrocarbons results in the splitting off of hydrogen and the formation of a complex mixture of liquid hydrocarbons. He mentions that rocks of the earth's crust are universally radioactive, although in very low intensity. The oily products formed under such circumstances are highly unsaturated. Lind considered this an objection to such a theory of petroleum origin. The unsaturated hydrocarbons could be polymerized, but the disappearance of hydrogen would be more difficult to account for In any case, the non-reactive by-product helium should persist Helium rarely occurs in natural gas and its occurrence, from about 0.5 to 2.0 per cent in some of the natural gases in northern Texas, western Kansas and Oklahoma, is to be explained by the proximity of old buried granite ridges and the Shinerump conglomerate of Colorado, which contains carnotite. (4) The gases richest in helium contain no hydrogen. In a private communication Lind states that he is unable to see any solution of the hydrogen and helium difficulty.

To assume that hydrocarbon gases, or methane, is the parent substance of petroleum would still leave unanswered the origin of the methane. Sheppard and Whitehead, (24) on the other hand, query the action of alpha radiation on the buried organic matter in the sediments. Their very painstaking and careful work shows that CO_2 is split out of fatty acids.

There can be no doubt, of course, of the experimental results. However, the principal objections to the theory that petroleums have been formed from either methane or buried organic matter in the sediments by radioactivity are probably as follows: (a) the composition of natural gas, the complete absence of hydrogen and only the occasional presence of helium; (b) there is no relation between the abundance of petroleum and natural gas and the proximity of radio-active minerals (intensity of alpha radiation); (c) the absence of olefinic unsaturated hydrocarbons in gases of petroleums. If the process is as stated to be, dependent upon the widespread radioactivity of low intensity, then the process must be a continuing one and unsaturated hydrocarbons and hydrogen would be expected. The most serious discrepancy between the observed facts and the alpharadiation theory is

that the outstanding experimental result of the action of alpha radiation on hydrocarbons is that it knocks off hydrogen atoms. Such continued action would produce progressively heavier oils poorer in hydrogen. This is quite contrary to the observed facts with respect to the geologically old, light paraffinic crudes (d) Optically active hydrocarbons in petroleum could not be expected, but petroleums do contain slightly optically active hydrocarbons. (e) Substance found in petroleums and derived from organic matter buried in the sediments, such as chlorophyll porphyrins, naphthenic acid complexes, nitrogen bases and labile sulfur complexes, must either escape destruction by alpha radiation or these substances must be picked up subsequently by the oil, possibly during migration. In 1944 Sheppard concluded, "In this survey of the origin of petroleum from the physicist's point of of view, no conclusions can be drawn as to whether or not radioactive processes are significant in petroleum genesis."

In this connection it should be noted that marine sahles, rich in kerogen, show exceptionally high radioactivity, but as already noted, such shales may be geologically very old, rich in organic material and contain little or no oil as such.

Finally, when oil (or gas) does come into contact with radioactive minerals extensive decomposition with carbon formation occurs as is shown by the mineral thucolite. In Canadian pegmatites, near Parry Sound, Ontario, and near Buckingham, Quebec, the mineral thucolite occurs, sometimes as a pseudomorph after uraninite. Analyses showed the mineral to contain 50.8 to 61.5 per cent carbon, about 2 per cent moisture, 20 per cent volatile hydrocarbons (gases) and 16.6 to 26.8 per cent ash consisting largely of uranium and thorium oxides. (26) Crevices and cracks in the adjacent pegmatite rock contained an oil substance which apparently had seeped into the pegmatite from the country rock subsequent to the intrusion of the pegmatite. Thus the action of the radioactive material on the oil was apparently extremely local and resulted in the formation of carbon and gases, a result to be expected from the experimental results showing splitting off of hydrogen.

SUMMARY

(1) A relatively low temperature history, through geologic time to the present, is indicated by the presence in petroleum of thermo-labile types of substances and by geological considerations. Temperatures within the range of 100° to about 250° F. have probably been the rule for most petroleum-bearing strata and source beds.

(2) The presence of chlorophyll porphyrins is also evidence of low temperature history, but this fact also shows that the material containing chlorophyll, probably marine algae or kelps, was deposited and preserved from aerobic bacterial action by rapid sedimentation. Petroleums containing porphyrins were probably derived from deposited organic material associated with green algae or kelps. Rapid sedimentation in relatively shallow, subsiding basins is also indicated by geological evidence.

(3) The chemical complexity of petroleums, together with the evidences of low temperature history, are best accounted for by *catalytic activity of active surface minerals*, particularly clays, with which oil has been in contact for long periods of time. Petroleums are not equilibrium mixtures produced by thermal action alone. The time element and evident geological history precludes oil or its source material ever having been heated to temperatures as high as 400° C.

(4) There is much evidence that low intensity radioactivity has had nothing to do with the origin of petroleum.

(5) Formation of hydrocarbons, other than methane by bacterial action, has not been demonstrated. Bacterial action undoubtedly occurred in the fresh sediments, as laid down, but later action to form hydrocarbons, is highly specu-

lative. Bacterial action cannot reasonably explain the complexity of petroleums as to number and types of hydrocarbons found in petroleums.

(6) Differences in original organic source material may explain the formation of coal, kerogen of shales and petroleums, including natural gas, as final end products. Such possible differences may account for some of the differences in petroleums, but cannot possibly account for the number and types of hydrocarbons found in typical petroleums.

(7) Fatty oils appear to be the most likely source material of petroleums, with proteins and cellulose probably also contributing.

(8) We lack chemical knowledge of the organic matter deposited in contemporary and recent sediments. Chemical investigation of organic matter in geologically recent strata should provide a chemical history of petroleum formation in intermediate transition stages.

(9) The formation of petroleum appears to have taken place in two general stages; first, an early stage, in which organic matter buried in marine sediments is chemically changed to material consisting largely of carbon and hydrogen but containing few hydrocarbons; second, a later stage in which a very large number of paraffins, isoparaffins, naphthenes and aromatics were formed by catalytic action of active surface minerals, including clays, at relatively low temperatures.

REFERENCES

(1) **Barton, D. C.** Problems of Petroleum Geology. Am. Assn. Petrol. Geol., *1934*, 109; J. Inst. Petr. Techn. *20*, 206 (1934).
(2) **Beeby-Thompson.** Oil Field Expl. & Development, London, 1925.
(3) **Bennett, J. G.** Trans. Inst. Chem. Engre, *1948*, 43.
(4) **Bottoms, R. R.** Science of Petroleum *2*, 1517 (1937).
(5) **Brooks, B. T.** Science of Petroleum *1*, 46 (1937).
(6) **Brooks, B. T.** Am. Ass'n. Petrol. Geol. *15*, 611 (1931); *20*, 280 (1936).
(7) **Conant, J. B.,** and **Petersen.** *Can. J. Res., 34*, 921 (1934).
(8) **Dobbin, C. E.** Am. Ass'n. Petr. Geol., *27*, 417 (1943).
(9) **Ells, S. C.** "Oil Shales of Canada," in Shale Oil, by R. H. Mckee, pp. 49. N. Y., 1925.
(10) **Engler, C.** *Ber. 21*, 1816 (1888); *30*, 2365 (1897); Zt. *f. angew Chem., 25*, 153 (1912).
(11) **Francis, A. W.** *Ind. & Eng. Chem., 20*, 277 (1928).
(12) **Frost, A. V.** *Chem. Abs., 1946*, 4499.
(12) (a) **Gayer, F. H.** *Ind. & Eng. Chem., 25*, 1122 (1933).
(13) **Heald, K. C.** Study of Earth Temperatures in Oil Fields, *Bull. Am. Petr. Inst., 1930*, 205.
(14) **Herington, E. F. G.,** and **Rideal, E. K.** Proc. Roy. Soc., London, **A** *184*, 434 (1945).
(15) **Lind, S. C.** *Science, 73*, 19 (1931); Science of Petroleum I, 39 (1937).
(16) **McCoy, A. W.,** and **Keyte, W. A.** Problems of Petr. Geol., *1934*, 253.
(17) **Nenitzescu, C. D.** *Chem. Abs., 33*, 4165 (1939).
(18) **Pyhala, E.** *Chem. Ztg., 57*, 273 (1933).
(19) **Rossini, F. D., Forziati, A. F., Willingham, C. B.,** and **Mair, B. J.** *Refiner*, November, 1943.
(20) **Rossini, F. D.** A. C. S. Meeting in Houston, December, 1947.
(21) **Russell, R. D.** *Am. Ass'n. Petr. Geol., 29*, 1470 (1945).
(22) **Sachanen, A. N.** "Chemical Constituents of Petroleum," pp. 201, Reinhold, N. Y., 1945.
(23) **Seyer, W. F.** *J. Inst. Petr. Techn., 19*, 733 (1933).
(24) **Sheppard, C. W.,** and **Whitehead, W. L.** *J. A. C. S., 68*, 1636 (1936); *J. Physical Chem., 50*, 119 (1946); *Am. Ass'n. Petrol. Geol., 28*, 924 (1944).
(25) **Smith, H. M., and Comm. Tulsa Geologists.** *Bull. Am. Ass'n. Petr. Geol., 1947*, 93.
(26) **Spence, H. S.** *American Mineralogy, 15*, 499 (1930).
(27) **Taylor and Turkevich,** *Trans. Faraday Soc., 35*, 921, (1939).
(28) **Treibs, A.** *Ann. d. Chem., 410*, 42 (1934); *517*, 172 (1933; *520*, 144 (1935); *Chem. Abs., 32*, 4482 (1938).
(29) **Washburne, C. W.** *Am. Ass'n. Petr. Geol., 3*, 345 (1919).
(29) (a) **Whitmore, F. C.,** and **Marshner, R. F.** Presented at Am. Chem. Soc. Meeting, April, 1935.
(30) **Zobell, C.** *Chem. Abs., 37*, 4092 (1943); Science, *102*, 364 (1945); *Bacteriol. Rev., 10*, 1 (1946).

THE BEDROCK SURFACE AND FORMER DRAINAGE SYSTEMS OF MONTGOMERY COUNTY, OHIO[1]

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INTRODUCTION

The bedrock surface of Montgomery County, Ohio (in which Dayton is situated), has been contoured in considerable detail. Elevations at more than 500 points on the bedrock surface were obtained in the course of a well survey conducted by the Ohio Water Resources Board and the U. S. Geological Survey in the summer of 1946. This survey was made to obtain data for a report on the water resources of the county, which is to be published in 1948 by the Ohio Water Resources Board.[2]

The bedrock underlying the glacial drift of Montgomery County consists of interbedded shales and limestones of Upper Ordovician age, capped over large areas by Middle Silurian limestones and dolomites. The rocks of both systems are so resistant that the casing in drilled water wells ordinarily can be driven only to the top of the bedrock surface. In wells that are drilled into the rock, therefore, the length of casing generally can be taken as the depth to the rock surface. In wells where the length of casing is the same as the total depth of the well it may be assumed that the well was finished in unconsolidated formations, bedrock not having been penetrated. In the field survey of wells these assumptions were used as a basis for acquiring the data for the bedrock contour map. The length of casing in wells was determined by means of an electrical device invented by the author and submitted for patent by the U. S. Department of Justice. The elevation of the rock surface was computed by subtracting the length of casing from the elevation of the land surface at the well, as shown by the topographic maps of the U. S. Geological Survey.

Montgomery County comprises parts of four quadrangles, namely, the Brookville, Dayton, Miamisburg, and Waynesville quadrangles. These quadrangle maps were used as a base on which to contour the bedrock surface. The accompanying plate is a reduced tracing of the bedrock contours developed on this base map. A full-scale copy of this bedrock contour map, showing 50-foot contour intervals, is to be included in Bulletin 12 of the Ohio Water Resources Board.

PREGLACIAL TOPOGRAPHY OF MONTGOMERY COUNTY

Before Pleistocene glaciation Montgomery County probably resembled the part of the Bluegrass region of Kentucky that lies just south of the glacial border. The topography of both areas is of similar origin with respect to the structure and stratigraphy of the underlying rocks. They are areas of regional uplift in which rocks of Upper Ordovician age, with a border of Silurian limestones, are exposed at the surface. The present Bluegrass area consists of a fairly smooth, gently rolling surface deeply dissected by short tributaries and broad, entrenched rivers, similar to the bedrock topography of Montgomery County. The covering of glacial drift over Montgomery County has subdued its former relief and masked all but the most prominent features of the ancient drainage.

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[1]Presented at the meeting of the Ohio Academy of Science, Toledo, Ohio, on May 7, 1948. Published by permission of the Director of the U. S. Geological Survey.

[2]Norris, S. E., Cross, W. P., and Goldthwait, R. P., The water resources of Montgomery County, Ohio: Ohio Water Resources Board Bull. 12 (in preparation).

BUTLER
CLARK
Arlington col
Englewood col
Somer col
WAYNE
RANDOLPH
HARRISON
PERRY
MADISON
MAD RIVER
DAYTON
JACKSON
JEFFERSON
VAN BUREN
GERMANTOWN
MIAMI
WASHINGTON
MAP OF
MONTGOMERY COUNTY, OHIO
SHOWING CONTOURS ON BEDROCK SURFACE
CONTOUR INTERVAL 100 FEET
ELEVATIONS GIVEN IN FEET ABOVE SEA LEVEL
SCALE IN MILES
0 1 2 3 4 5 6
EXPLANATION:
• LOCATION OF WELL DATA
▲ BEDROCK OUTCROP
GEOLOGY BY S.E. NORRIS
JK

PREGLACIAL (TEAYS STAGE) DRAINAGE IN MONTGOMERY COUNTY

The earliest recognizable drainage system in Ohio is called the Teays system and all streams in existence at that time are referred to as "Teays Stage" drainage.[3] The Teays system, it is thought, antedated the earliest of the glacial stages of the Pleistocene epoch. The master Teays River rose in the Piedmont area in the southeastern part of the United States and flowed across Ohio in a northwesterly direction in a course that lay a few miles north of Montgomery County. The Teays drainage system must have endured for a considerable length of time, for the streams eroded broad, deep channels and developed an immature peneplain or base level known as the Parker Strath.

Montgomery County, because of a drainage divide in its northern part, was drained only partially by the main Teays River. The greater part of the county was drained by a large Teays tributary named by Stout [4] the Hamilton River. The Hamilton River flowed southward through Montgomery, Butler, and Hamilton Counties, then turned westward and entered the Teays River somewhere in Indiana.

The former course of the Hamilton River through Montgomery County is defined by the bedrock contours shown on the accompanying plate. In Teays time it entered Montgomery County from the east near the boundary line between Mad River and Van Buren Townships. From this point the Hamilton flowed northwestward to about the Middle of Mad River Township and from there it flowed westward to Dayton, cutting that part of its valley now occupied by the Mad River. At the site of Dayton the Hamilton River received from the north and northwest the waters of three large tributaries whose courses are now occupied by the Miami River, which flows in part along the western border of Wayne Township; the Stillwater River, whose present course is in part along the western border of Butler Township; and Wolf Creek, which flows through Madison Township. In Teays time these tributaries terminated in the uplands of Montgomery County in col areas respectively at Tadmor, Englewood, and Arlington. The valleys on the northern sides of these cols were cut by north-flowing tributaries of the main Teays River.

From Dayton to the southeastern corner of Jefferson Township the Hamilton River cut a broad course that is now occupied by the Miami River. The course of the Hamilton from that point was westward through the southern part of Jefferson Township, and thence southward through the eastern part of German Township to the county line. In the southwestern part of Jefferson Township the Hamilton was joined by two large tributaries, both of which entered Montgomery County from the west.

A col or drainage divide existed in Miami Township in Teays time, at the site of the city of Miamisburg. This col separated two short opposite-flowing Hamilton tributaries. Two other cols existed in north-central German township.

The width of the Hamilton River valley in Montgomery County, as shown by the map contours, averaged more than 1 mile at river level and up to 3 miles at the divide levels. In Teays time the main stream was entrenched some 200 feet below divide levels.

In Montgomery County streams of later drainage stages greatly deepened the valleys originally developed in Teays time and only a few scattered remnants of the Teays valley levels are now to be found. These remnants of the Teays valley floor occur as terraces along the sides of some of the more recent valleys at elevations ranging from 750 to 770 feet for former tributaries in the northern part of the county, to elevations as low as 650 feet along the main stream in the

[3] Stout, Wilber, Ver Steeg, Karl, and Lamb, G. F., Geology of Water in Ohio: The Ohio Geological Survey Bull. 44, 4th Ser., 1943.

[4] Stout, Wilber, Ver Steeg, Karl, and Lamb, G. F., *op. cit.*

southern part of the county. Not enough well records are available to determine the gradient of the floor of the main Teays-stage Hamilton valley.

The existence of the Teays drainage system, according to Stout and others,[1] was terminated by the advance to the central Ohio area of a very early pre-Illinoian glacier, perhaps of the Kansan stage. This early glacier, it is thought, did not reach the area of Montgomery County, but it did advance to a point where it blocked the main Teays River to the north. This caused major diversions of the drainage lines and inaugurated the succeeding "Deep Stage" drainage system. The Deep Stage system is so called because during this time the streams cut deep, narrow valleys many feet below the levels established in Teays time. This down cutting might have resulted in part from regional uplift of the land surface shortly after the start of the Deep Stage drainage cycle.

DEEP STAGE DRAINAGE IN MONTGOMERY COUNTY

It seems evident that the Hamilton River in Deep Stage time persisted in its original course in Montgomery County, as did its principal tributaries. Well records at several points in the Hamilton valley in Montgomery County show no evidence of lake deposits, indicating that the south-flowing Hamilton River probably was not ponded by the pre-Illinoian glacier, as were parts of the main Teays system. The cols at Tadmor, Englewood, and Arlington might have been cut through in Deep Stage time with the extension northward of three Hamilton tributary valleys. The reduction of these cols, if it happened in early Deep Stage time, might have resulted from the overflow of waters from ponded Teays valleys to the north. Available well records in the valleys north of these cols in Montgomery County show a considerable thickness of very fine sand, but no silts or lake clay deposits. Apparently, if ponding did occur, any lake deposits in these valleys must have been of small extent or were removed by later streams before the glaciers deposited their materials.

Deep Stage valleys in Montgomery County are comparatively wide, perhaps as much as a mile in the Hamilton valley. The lowest elevation of the valley floor recorded at Dayton is about 503 feet above sea level, nearly 200 feet lower than the Teays level. A test well in southeastern Jefferson Township, and thought to be near the axis of the Deep Stage channel, struck bedrock at the depth of 212 feet, or at an elevation of about 500 feet above sea level. If this point and the one at Dayton are in the deepest parts of the valley, a gradient of about 1 foot per mile is indicated for the main Hamilton valley in Deep Stage time, which is probably too low.

EFFECTS OF GLACIATION ON THE DRAINAGE IN MONTGOMERY COUNTY

The Illinoian glacier, the first ice sheet to cover Montgomery County, ended the Deep Stage drainage cycle and began a new drainage system which was probably much like the present system as it has evolved since the more recent Wisconsin glaciation.

It is probable that the Illinoian glacier caused a minor drainage diversion in the west-central part of Miami Township, where it forced the main Hamilton drainage through a narrow col which in Teays and Deep Stage times had separated two short tributaries. Drainage diversions were likewise caused in German Township where two smaller cols were breached by ice-diverted drainage or by melt water from the glacier. It is also possible that the cols at Tadmor, Englewood, and Arlington were cut through in this way.

The work done by the post-Illinoian streams consisted mainly of the removal of part, and in some areas probably most, of the valley deposits laid down by the

[1] Stout, Wilber, Ver Steeg, Karl, and Lamb, G. F., *op. cit.*

Illinoian glacier. The post-Illinoian interglacial period was brought to a close by the advance of the Wisconsin glacier, the latest ice sheet to cover this area.

The Wisconsin glacier probably caused some changes in the drainage lines of post-Illinoian time in Montgomery County. Perhaps the Wisconsin ice caused some of the changes in the Deep Stage system that are credited herein to the Illinoian glacier. It is believed, however, that the main effect of the Wisconsin ice sheet on the former drainage was in supplying the greater part of the unconsolidated materials that now fill these valleys.

It is planned by the Ohio Water Resources Board and the U. S. Geological Survey to extend a well survey, such as the one completed in Montgomery County, into the adjacent counties of Greene, Clark, Miami, and Champaign. Detailed maps of the bedrock surface in these areas will undoubtedly help to define in detail the drainage history of the entire southwestern part of Ohio.

Genetics, Medicine, and Man

This book contains the text of six Messenger Lectures, two by each of three eminent geneticists, talking from his own research experience on the given tripartite subject. Dr. Muller presents the fundamentals of genetics with simple language in a manner that provides a refreshing review, especially for anyone whose only previous contact with genetics has been by way of the complexities of an elementary text book course. The effects of the mechanism of sexual reproduction on evolution are discussed in relation to directing them toward long term human welfare.

Dr. Little defines genetics as "the science of studying parental influence upon offspring." He takes a broad view to the extent of including items which orthodox geneticists would classify as purely environmental (non-generic) influences. For convenience, he distinguishes three overlapping categories of influence: morphogenetic, endocrine-emotional, and psycho-social. The simple points which he makes in plodding complicated style are: that every gene is always in some kind of an environment, and, that such things as physiological reactions, emotional stability, and social behavior are affected by genes as well as by environment. The advantages of seeking knowledge of man indirectly through a study of laboratory mammals over studying humanity directly are emphasized.

Dr. Snyder's fine style provides a satisfying finale for the book. It deals with the segment of the theme which will be of most interest to non-geneticists. He points out the direct, practical applications of genetics to man that are already being made. A discussion of some of the special problems which the study of human heredity presents and examples of some methods through which they are being outmaneuvered are explained. Genetic maps of human chromosomes are illustrated.—*Elton F. Paddock.*

Genetics, Medicine, and Man, by H. J. Muller, C. C. Little, and L. H. Snyder. 158 pp. Ithaca, New York, Cornell University Press, 1947. $2.25.

SOME WILDLIFE AND LAND USE RELATIONSHIPS IN OHIO

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Although the first white people who came into the Ohio Territory as hunters and trappers probably gave little or no thought to conserving, propagating or managing wild animals, it was relatively early in Ohio's history when laws were first passed to protect economically important animals. As indicated in a companion paper by Dambach to be published in a later issue of this Journal, a law was passed in 1829 to protect the valuable fur-bearing muskrat during its reproductive season. This was followed in succeeding years by other protective or restrictive legislation establishing seasons and daily bag limits according to game abundance and regulating the manner in which animals could be killed legally.

Protective legislation is only one of several methods man has used to manage wildlife species. Artificial propagation of game and fish, followed by stocking has been and still is popular with Ohio sportsmen, although numerous studies have shown that game farm birds and hatchery fish supply only a fraction of the annual harvest. Refuges have been established to provide sanctuary to game animals during and following the hunting season so that ample brood stock might remain for the following year. Such areas have been of particular value to the ring-necked pheasant and waterfowl. Granted that refuges, restocking and protective legislation play their part in wildlife management, it is apparent that in the present plight of our pheasants, our waterfowl and our Hungarian partridges, these measures have not been entirely successful.

One of the most promising management techniques is that of habitat improvement. This method is based on the hypothesis that when the environmental requirements for a given animal are satisfied it will be able to approach its biotic potential and be present in goodly numbers; conversely, if the habitat is not satisfactory, no amount of stocking or protection will result in sustained high populations of the animal. Obviously, exotic species such as our ring-necked pheasant and Hungarian partridge would not be in Ohio today if the habitat had not been suitable for their existence when they were stocked.

The Ohio Division of Conservation and Natural Resources in recognition of the necessity of providing suitable wildlife habitat, initiated a program of habitat improvement throughout Ohio in 1947. It is the purpose of this paper to indicate important wildlife-land use relationships which are involved in the development of a wildlife management program in Ohio.

WILDLIFE DURING OHIO PIONEER DAYS

Although frequent accounts were written by the early Ohio settlers concerning some of the more conspicuous animals inhabitating the area, little accurate information was recorded concerning the smaller and often more inconspicuous birds and mammals. Even today when much attention is given to the censusing of wild animals we still have but little accurate information on wildlife populations.

[1]The author wishes to express appreciation and thanks to Dr. Charles A. Dambach, the Ohio State University; Dr. Lee E. Yeager, the Fish and Wildlife Service, and Dr. Floyd B. Chapman and Mr. E. L. Wickliff, the Ohio Division of Conservation and Natural Resources, and Mr. E. S. Thomas of the Ohio State Museum, for their helpful suggestions in the preparation of the manuscript. Dr. O. D. Diller of the Ohio State University kindly made available the print showing the distribution of forests and woodlots in Ohio.

[2]The Ohio State University, the Ohio Division of Conservation and Natural Resources, the U. S. Fish and Wildlife Service and the Wildlife Management Institute cooperating.

We know that Ohio was originally a forested area (± 95 per cent) with a relatively small amount of prairie and marsh land. We know that several mammals once present in Ohio, including the fisher, timber wolf, wildcat, porcupine, snowshoe rabbit, American elk, bison, panther and marten, were extirpated because of habitat destruction, hunting or for other reasons. We also know that many birds that once occurred in Ohio are no longer present. These include the wild turkey, greater prairie chicken, raven, whooping crane and swallow-tailed kite, which although extirpated from Ohio are still found in parts of the United States; and the passenger pigeon, Louisiana paroquet and the Eskimo curlew, which are not extinct.

The American Indians, who lived in, or visited the Ohio territory before the white man came, were hunters and small scale farmers. They are said to have occasionally burned off small areas and raised some corn, beans and pumpkins. Their inroads on wildlife were of much importance to their own welfare but probably had little effect on the fish and game populations.

With the coming of the White man to the Ohio territory, habitat conditions then existing were altered. The early settlers reached considerable numbers first along the Ohio River and its tributaries and along the southern shore of Lake Erie. In 1800 there were only 45,000 white men in the territory. The Indians were forced out of the state about 1845. By 1850 most of the counties in the eastern half of the state had reached their maximum rural population (Beck 1934). Settlement was practically complete by 1880 except for a few areas, most of which were in the poorly drained Maumee plain of northwestern Ohio. It was here that many of the larger forest species were last reported in Ohio. In 1840 agriculture was still the chief industry, but by 1930 Ohio had become an industrial state with less than one-sixth of its population living on farms (Beck *op. cit.*).

The most marked ecological change produced by the settlement of Ohio came as a result of the clearing away of the forests which began in the southeastern counties about 1788. The land was cleared not only for agriculture, but also in the interest of mining, salt and steel industries, which required large supplies of wood for mine props, fuel and charcoal. By 1890 forest clearing in Ohio was nearly complete, the rural population had reached a maximum and some of the earliest cleared land in southeastern Ohio was already being abandoned. (Sitterley and Falconer, 1938).

SOME HABITAT CHANGES RESULTING FROM THE SETTLEMENT AND DEVELOPMENT OF OHIO

Disappearance of forest cover and the plowing of the virgin soil (all too frequently up and down the slopes) accelerated erosion. The streams became silt laden and flooding was possibly more frequent and extensive. By the mid-1930's about 32 per cent of the state was affected by moderate sheet erosion and 16 per cent, mostly in east central and southeastern Ohio, was severely eroded. (Conrey, Cutler and Paschall, 1937).

Clearings made by the first pioneers were only small openings in the forest. In the more rugged sections of southern and eastern Ohio the remaining wooded areas later assumed a dendritic pattern, following streams, steep-sloped ravines and rough terrain. Forest edge thus provided was especially valuable for such species as the bob-white quail. In the more level areas of north-central and northwestern Ohio, 80 to 90 per cent of the woods were eventually removed leaving scattered, rectangular woodlots separated by much larger blocks of open farm lands with a few connecting arms or brushy fencerows to be used as travel lanes by wild animals.

In addition to the cutting of the forests, the draining of sizeable swamp and marsh lands in northern Ohio greatly altered the wildlife habitat and converted the former into some of the richest agricultural land of the state. In Wood County alone there are now more than 2,000 miles of open drainage ditches. These ditches provide travel lanes, cover and food for many animals including muskrats, which feed on the crops (corn, soybeans, alfalfa, etc.) now grown in adjacent fields.

Forest cover of Ohio. "Prepared by Forest Survey, Ohio Agricultural Experiment Station, Wooster, in cooperation with Central States Forest Experiment Station, Columbus. Map compiled from aerial photographs provided by Agricultural Adjustment Administration. Black areas indicate woodlands." (See Ohio's Forest Resources, Forestry Publication No. 76. Ohio Agr. Expt. Sta. and Central States Forest Expt. Sta.)

With the rapid growth of cities and industrial plants in Ohio, wastes, both human and industrial, were poured into Ohio streams, often affecting fish and other aquatic life adversely. Mr. E. L. Wickliff, Chief of the Fish Management Section of the Ohio Division of Conservation and Natural Resources, in conversation January 25, 1948, stated that fish may be exterminated locally as a result of habitat changes but few have been completely extirpated from Ohio and a few have been introduced by man.

The streams (some 12,000 miles of them) which flowed through Ohio's virgin forests were probably cooler and clearer than those now present. They probably had frequent pools and eddies due to trees falling across them, and they also probably had an bundant food supply for fish. The silt and mud found in our streams are there today because of erosion. The suspended silt particles tend to absorb more of the sun's rays, thus making the water warmer, and through reduced photosynthesis, decrease the amount of aquatic vegetation and other organisms available for fish food. Langlois (1941) pointed out these and other relationships obtaining in the southwestern part of Lake Erie and indicated the adverse effect silt had on ciscoes, whitefishes and yellow perch.

Originally there were only ten to twelve square miles of impounded water (lakes) in the Ohio area. Today there are more than 100 square miles of such water with many farm ponds and lakes under construction and others projected for future building. Thus the habitat for such species as the white crappie, blue gill, largemouth bass, channel catfish, bullhead catfish, pumpkinseed, black crappie and yellow perch has been greatly increased.

SOME CHANGES IN OHIO FAUNA RESULTING FROM HABITAT ALTERATIONS

We have seen that Ohio was changed, through settlement, from what was once primarily a deciduous forest environment, to an agricultural land with prairie-like characteristics. Many typically forest animals were extirpated while other animals, more adapted to the new environment, moved into Ohio or increased in numbers after the country was settled. Among the mammals which are more abundant in Ohio than originally are the thirteen-lined ground squirrel or spermophile, prairie white-footed mouse, meadow mouse or vole, badger, and the introduced Norway rat and house mouse. The cottontail rabbit, skunk, opossum, muskrat, fox squirrel and prairie mole are also probably much more common now than formerly. There is apparently some question about the occurrence of the red fox in the Ohio area before the White man came. If it did occur originally, it was less abundant than at present.

The vesper, field, Savannah, grasshopper and Henslow's sparrows, and the dickcissel, bobolink and prairie horned lark have evidently benefited from the changed Ohio environment and are more abundant than formerly. Other birds such as the robin, housewren, nighthawk and the introduced English sparrow and starling became adapted to man's settlements and greatly increased in numbers. The red-winged blackbird now frequently nests in alfalfa and red clover fields, cover types which were not available in the Ohio wilderness area. Among the more southern species which have extended their ranges northward are the Carolina wren, cardinal, tufted titmouse, mockingbird and chuck-will's widow

Such fishes as the bluegill, crappie and large-mouthed bass which are adapted to living in lakes and ponds are much more abundant than originally due to the increased habitat resulting from man's pond and lake building activities. Some changes in fish distribution have also taken place. Mr. E. L. Wickliff reports that the sucker-mouth minnow apparently invaded Ohio from the west and is adapting itself to the streams of central and eastern Ohio. Also with the building of Ohio canals the white crappie moved northward in the state.

In general what has been said about the changes occurring in the population of mammals, birds and fish probably also applies to insects and other forms of life,

namely, forest species have decreased in numbers, whereas prairie species such as many of the leafhoppers, grasshoppers and plant bugs have increased. Although many of the economically important insects are exotics, having been accidentally introduced here by man, the chinch bug is a native species that originally lived in the corn belt area where it infested prairie grasses such as *Andropogon* sp. Man plowed up this area and planted the cultivated grasses, wheat and corn. The chinch bug became adapted to the new conditions and now attacks both plants.

This brief summary of changes brought about by civilization indicates some of the general relationships existing between man and wildlife. It indicates how man can drive out animals by destroying or altering habitat and how, often unwittingly, he can create new habitat conditions which will enable other animals to live and multiply in number.

Although Ohio's wildlife belongs to the people of the state, the bulk of the wildlife (probably more than 90 per cent) is produced, as an unplanned crop, on privately-owned lands. It is obvious that the landowner is in a key position to manage wildlife, and the State, which owns only a small percentage of the land in Ohio, must either devote its efforts to managing this small publicly owned area or to working through the landowner in any program which involves extensive wildlife habitat development. The landowner has but little incentive to produce more game on his land under present day conditions when, in most instances, he receives no remuneration from the hunters and when, as he realizes, the more game he has on his property the more people he will have hunting or asking to hunt on his land. The farmer knows also that many, though not all, of the wildlife management measures he can practice, take land out of crop production and thus cost him money. The owners of some waterfowl and muskrat marshes have learned that they can manage the marshes for profit. They harvest the muskrats and charge fees for waterfowl hunting privileges. Fortunately for the "one-gallus hunter", most landowners are quite willing to permit upland game hunters on their property as guests as long as they respect the property and behave as true sportsmen.

In developing a program of game management in Ohio the land use—wildlife relationships mentioned below should be recognized. Obviously, since game is a secondary crop in Ohio, most of the agricultural practices affecting wildlife will be altered for the benefit of wildlife only insofar as the landowners are assisted in their game management efforts or are shown that certain management measures are beneficial to their interests.

1. *Cultivated crops as wildlife food*

Yellow corn is probably the most important wildlife food in Ohio, being consumed by pheasants, squirrels, raccoon, muskrats, deer and many other animals. Of great importance also are wheat and soybeans. The production of these crops has increased during recent years in much of Ohio. In six pheasant belt counties, for example, the acreage devoted to soybeans was increased 78.9 per cent from 1940 to 1945, while corn and wheat acreages were increased 5.0 and 15.6 per cent respectively (Ray et al., 1943, 1946). Smartweed, lesser ragweed and fox-tail grasses commonly associated with these crops are also excellent wildlife foods and increase in abundance as the acreages in row crops increase. Extensive use of herbicides such as 2, 4-D may, however, materially reduce this source of food and cover in the future.

2. *Harvesting methods as they affect the availability of cultivated crops for wildlife foods*

Mechanical corn picking is rapidly taking the place of the cutting and husking method of corn harvesting. Field observations in a large part of the pheasant belt of western and northwestern Ohio indicated that only about 10 per cent of the corn was picked in 1936 compared to 70 per cent in 1946. Since most of the picked

corn is now harvested by machine instead of by hand, and since mechanical pickers leave more waste grain in the fields than the other methods, the increased use of machine pickers has resulted in an increased amount of waste corn, available except under ice and deep snow, as wildlife food.

Soybeans, when grown for hay, pasture or green manure, are of relatively little direct value to wildlife but when combined for grain the waste beans are utilized by pheasants, rabbits and other animals as food. According to Ray *et. al.*, (1943) the percentage of soybeans in Ohio which was harvested for grain increased from 49.1 in 1936 to 73.0 in 1941. The author (Leedy 1939) found by sampling fields in Wood County, Ohio, an average of approximately 292 pounds of corn left per acre in machine-picked corn fields and 227 pounds of soybeans per acre in combined soybeans. He also found smartweed seed produced at an average rate of more than 47 pounds per acre in corn and soybean fields sampled and ragweed seed at a rate of approximately 86 pounds per acre in unclipped wheat stubble. It is thus apparent that much food in the form of waste grain and weed seeds is available to wildlife in intensively farmed areas where the limiting factor is likely to be lack of adequate wildlife cover.

3. *Agricultural Crops as Wildlife Cover*

Since agricultural crops constitute the bulk of the cover now present in Ohio it is expected that they should be used as such by wild animals. Such cover is at a maximum during midsummer but is gradually reduced by harvesting, stubble clipping and plowing so that only a relatively small amount is left by March. Wild animals shift from field to field until by spring they are often concentrated in a semi-permanent type of cover consisting of a few brushy fencerows, woodlots, ditch banks, and idle fields. Spring burning of ditch banks, fencerows, and roadsides reduces this cover still further.

During the years 1939 to 1941 nesting studies made in the Ohio pheasant belt by the Ohio Wildlife Research Unit indicated that approximately two-thirds of the pheasants nested in hay meadows. Many rabbits also have their nests in meadows. According to Ohio Agricultural Statistics (Ray el al., 1946) there was a reduction of 24.4 per cent in hay acreage in six Ohio pheasant counties from 1940 to 1945. This trend has probably been detrimental to pheasants and other birds such as the red-winged blackbird, sparrows, dickcissel, and meadowlark which nest in meadows. For example, studies made in southwestern Ohio (Dambach and Good, 1940) indicated about 50 pairs of breeding birds per 100 acres of meadow compared to an average of ten pairs per 100 acres of small grains.

Unclipped wheat stubble left by combines provides excellent roosting sites for pheasants throughout the fall and even during the winter and early spring months. Standing corn also provides superior cover; it is frequented by pheasants, rabbits, bob-white quail and other animals. Although machine pickers break over the corn stalks, more cover is left in the fields than when the corn is cut and husked or put into silos.

4. *Ohio woodlots and forest areas in relation to wildlife*

Although woodlots and forests now constitute only about 14 per cent of the total land area in Ohio (Pl. I) they provide the year around home for many animals and the part time home of several other animals. In the more heavily forested area of eastern Ohio white-tailed deer and beaver are reappearing and extending their range after having been extirpated. Based on the estimate of game protectors there was approximately 9,300 deer in Ohio, 1947 as compared with 4,400 reported in 1943, indicating an increase of 114 per cent in four years (Leedy, 1947). According to Sitterley (1944), during the first 40 years of the present century the number of farms in the southeastern third of Ohio dropped from 86,759 to 73,073 and the land in farms from 8,148,134 acres to 6,949,919 acres. The shift in land use

from farms to woodland is apparently still in progress and there are approximately 1,500,000 acres of marginal or submarginal land best suited to be in forest, bringing the potential woodland area of Ohio to 5,207,598 acres or one acre in woods out of every five acres of land area (Diller, 1944). The retirement of farm units and the increased acreage of forest land are providing more habitat for grouse, gray squirrels, deer and beavers.

In the larger, glaciated section of Ohio most of the forest cover is in the form of isolated woodlots. In the western part of the state more than three-fourths of these woodlots are pastured. Woodlot pasture is inferior in quality and quantity to rotation pasture. The practice of woodland pasturing is not only detrimental to most forms of wildlife but reduces the production of other forest products including lumber, fire wood and maple syrup.

Dambach (1944) found, in comparing a grazed and an ungrazed woodlot in Geauga County, Ohio, that for a five-year period breeding birds in the ungrazed area were four times more abundant and represented twice as many species as those in the grazed woodlot. He estimated that there were 81 mammals per acre in the ungrazed as compared to 49 per acre in the grazed woodland at the end of a ten-year period. In Butler County in southwestern Ohio, Dambach and Good (1940) found approximately twice as many pairs of breeding birds in unpastured as compared with pastured woodlots.

The author, working in Wood County, Ohio, in 1937 recorded 19,891 pheasants of which 23.6 per cent were seen in woodlots. The woods were apparently of greatest value in the winter, when 37.3 per cent of all pheasants seen were in that type of cover, and least utilized in summer, when only 5.4 per cent were in woods. More than three-fourths (76.9 per cent) of the pheasants seen in woods were within 25 yards of the outside edges. Woodlots harboring the most pheasants were ungrazed, or if grazed, had patches of wild roses, brambles, prickly ash, *Crataegus* or other protective cover in them. In addition to providing cover of much value to pheasants in the winter and early spring, woodlots are also used for roosting sites and to some extent for feeding and nesting sites.

The fox squirrel, an animal of the prairie edge, is undoubtedly more abundant in Ohio now than under the original forested conditions. It is able to live in farm woodlots on hickory nuts, acorns, beechnuts, black walnuts, buds and other natural foods, often supplemented by corn grown in adjoining fields.

5. *Field borders in relation to wildlife*

Next to woodlots, field borders provide the most extensive semi-permanent type of cover available to wildlife in Ohio. They offer some of the best possibilities for developing a wildlife habitat improvement program. They are of much value in providing various types of cover and food for animals living part or full time in such cover and they also function as travel lanes for animals in going from one area to another. Field border travel lanes thus make it possible for some animals to utilize areas that would otherwise be unavailable to them.

Many investigators have noted the value of brushy field borders in providing cover for birds. In Ohio, Dambach (1945) found that field borders composed largely of woody plants, are occupied by many more nesting birds and beneficial mammals such as the short-tailed shrew than are nonwoody borders. Conversely he found that borders, consisting largely of blue-grass, supported high populations of destructive species such as the meadow vole, pine mouse, lemming, prairie white-footed mouse and house mouse. In Wood County, Leedy (1940) found that dense, brushy fencerows were utilized by pheasants in winter 30 times more than clean fencerows in the same area. The brushy fencerows were also found to be much more valuable as travel lanes than clean or sodded field borders.

In intensive field border studies made in southwestern Ohio, Dambach (1945) learned that shrubby fencerows less than four feet in width and six feet in height

had little effect on the yields of adjacent crops. He found that "the more nearly the vegetation in a crop field border is related to the adjacent crops, the greater is the danger of its serving as a center for infestation of crops by insect and small mammal pests". It seems obvious from these findings that some type of shrubby field border is to be desired for wildlife between or adjactent to grain and forage crops and that sod or herbaceous types of field borders are less harmful around orchard crops. Dambach's studies also point out the need for further research in developing shrubby plants that will be easily managed, provide adequate wildlife cover and not compete with adjoining crops.

Fences of one type or another become an essential part of the farm habitat whenever livestock is included in the agricultural program. For the most part there is some conflict or competition between livestock and wildlife. Pasturing, cutting and burning are the three practices which are responsible for keeping more than one-half of Ohio's fencerows so clean that they contribute little to the production of game animals. Cutting, burning and other fencerow cleaning operations have been shown to be effective in controlling only a relatively few crop pests but these operations effectively reduce food and cover for wildlife and result in some mortality and nest destruction. Obviously most fences are built to hold stock or to form property lines between farms. The ratio of fenced and fenceless field borders serves as an indicator of the relative amount of pasturing done in different counties. In livestock and dairying areas the percentage of fields with fences is high; in cash grain crop areas the percentage of fields with fences is relatively low.

In 1939–1940 a survey (Leedy, 1940) was made of some 16,800 fencerows in 24 counties scattered throughout Ohio. This study indicated that unfenced, and therefore unpastured, field borders often contained more cover than fenced field borders.

In Wood County, it was found that only 38 per cent of the fields were separated by fences compared to 93 per cent in Madison County. Wood County has a relatively high pheasant population and Madison County, a relatively light pheasant population. It is likely that the different agricultural practices followed in these counties and reflected in the number of pastured fields are partly responsible for the differences in the population of pheasants and other wildlife.

During the 1939–1940 survey fencerows were evaluated according to their potential winter cover for pheasants. Only 816 of them (4.8 per cent) were considered as providing superior winter cover consisting largely of shrubs, sprout growth and briers. Dambach (1945) recorded only 5.9 per cent of the field borders in his study area as shrub borders. It is apparent that much remains to be done to develop Ohio's field borders so that they will contribute to larger wildlife crops.

Interesting also are the kinds of fences observed in the above-mentioned survey (Leedy, 1940). Of 2,692 fences classified in 20 Ohio counties, the following percentages were noted by type: wire, 81.94; barbed wire, consisting of two or more strands, 13.71; electric, 1.75; rail fence, only .67; other fences, 1.93. The decrease in use of the rail fence has very probably been detrimental to such species as chipmunks. Electric fences have been unfavorable to wildlife inasmuch as they make it possible to quickly fence an area for pasturing and result in fewer permanent field borders. A survey made in Wood County, 1938, showed that approximately 15 per cent of the corn fields were pastured after having been picked. Of these pastured corn fields 42 per cent were partially or entirely enclosed by electric fences (Leedy, 1939).

6. *Miscellaneous practices and trends as they affect wildlife*

In addition to the wildlife-landuse relations pointed out above certain other practices and trends should be mentioned. Among these are the soil conservation practices including strip cropping, contour cultivation and land planning in which

acreages of row crops are reduced and acreages devoted to forestry, wildlife and pasture are increased. Soil conservation practices resulted in net gains of 37.7 per cent and 44.9 per cent respectively of breeding birds on demonstration areas in southeastern Ohio and southwestern Ohio (Good and Dambach, 1943).

In the northwestern Ohio oil fields in former years, thousands of "rod lines" radiated from hundreds of engines transmitting power to the oil well pumps. These iron rod lines cut across fields in such a way that numerous odd corners were left to grow up to weeds and brush thus providing valuable game coverts in addition to the strips of cover left along the rod lines themselves. These rod lines are being taken up now that the oil is gone and large fields are being substituted for the numerous small and odd-shapped fields that once provided a greater variety of cover.

Strip-mining is becoming more general in the eastern Ohio coal fields. Thousands of surface acres have been and are being stripped of coal by power shovels which leave the raw overburden in series of steep-sloped ridges. Studies now being made in Ohio by Charles V. Riley, graduate student at the Ohio State University, as well as investigations made in other states indicate good possibilities of developing these areas for wildlife and forestry.

The development of new varieties of agricultural crops have both beneficial and detrimental effects on wildlife. Generally speaking the greater the yield of a given crop the more waste there will be left as wildlife food when the crop is harvested. However, some of the hybrid corn now grown, for example, stands up better and is picked cleaner than older varieties which yielded less per acre. An earlier maturing variety of timothy (Huron) is now being grown on a small scale in Ohio. If timothy and other hay crops were harvested earlier, the destruction of pheasant nests would be greater than it is now since more unhatched nests would be present at haying time.

Harvesting methods are an important influence on wildlife because of their effect on food and cover as pointed out earlier and also because of the resulting destruction to wild animals and their nests. Pheasant casualties as a result of hay mowing increased approximately 60 per cent from 1938 to 1946 mainly because of the increased use of power mowers. Careful counts made in 590 acres of alfalfa cut for Wood County dehydrating mills in 1946 revealed 106 adult female pheasants and 74 juvenile pheasants which had been killed by mowers. A total of 193 other dead vertebrates including 37 cottontail rabbits, were also killed. (Leedy and Dustman, 1947).

The destruction of unhatched nests together with such casualty rates indicate the importance of establishing undisturbed nesting areas as a part of a pheasant and rabbit management program. Investigations devoted to the development of an efficient type of flushing bar which would save many of these animals from being killed, would also seem to be justified.

The practice of clipping small grain stubble fields following the harvest is becoming more prevalent. Clipping the stubble reduces the amount of fall and winter cover available, decreases the amount of food and apparently decreases the attractiveness of the cover in the next year's hay crops for pheasant nesting.

SUMMARY

1. Protective and restrictive game legislation, artificial propagation and restocking of game, and establishment and maintenance of game refuges have been inadequate in keeping the supply of game in Ohio sufficiently high to meet the growing demands of the hunters.

2. Recognizing the food and cover requirements of the species, habitat development is recommended as a practical approach to the problem.

3. Changes in the Ohio environment due to settlement and development have brought about marked changes in the flora and fauna. Many typically forest

animals were extirpated, while other animals, more adapted to the changed environment, moved into Ohio or increased in numbers after the country was settled.

4. Although Ohio's wildlife is held in trust by the State for all the people, the bulk of the wildlife is produced as an unplanned crop on privately-owned farms.

5. The landowner is in a key position to manage wildlife through his control of the natural habitat but has little incentive for so doing without some assistance, financial or otherwise, from the army of sportsmen which desires hunting privileges.

6. Wildlife-land use relationships which are involved in the development of a wildlife management program based on habitat improvement, are discussed under the following headings: (a) cultivated crops as wildlife food; (b) harvesting methods as they affect the availability of cultivated crops for wildlife foods; (c) agricultural crops as wildlife cover; (d) Ohio woodlots and forest areas in relation to wildlife; (e) field borders in relation to wildlife and (f) miscellaneous practices and trends as they affect wildlife.

LITERATURE CITED

(1) **Beck, P. G.** 1934. Recent trends in the rural population in Ohio. Ohio Agr. Expt. Sta., Bull. No. 533, pp. 1–41.
(2) **Conrey, G. W., J. S. Cutler** and **A. H. Paschall.** 1937. Soil erosion in Ohio. Ohio Agr. Expt. Sta., Bull. No. 589.
(3) **Dambach, C. A.** 1944. A ten-year ecological study of adjoining grazed and ungrazed woodlands in northeastern Ohio. Ecological Monographs 14: 255–270.
(4) ———. 1945. Some biologic and economic aspects of field border management. Trans. 10th N. Amer. Wildlife Conf., 170–184.
(5) **Dambach, C. A.,** and **E. E. Good.** 1940. The effect of certain land use practices on populations of breeding birds in southwestern Ohio. Journ. Wildlife Management, 4: 63–76.
(6) **Diller, O. D.** 1944. Ohio's forest resources. Forestry Publication No. 76, Ohio Agr. Expt. Sta. and Central States Forest Expt. Sta.
(7) **Good, E. E.,** and **C. A. Dambach.** 1943. Effect of land use practices on breeding bird populations in Ohio. Journ. Wildlife Management, 7: 291–297.
(8) **Langlois, T. H.** 1941. Two processes operating for the reduction in abundance or elimination of fish species from certain types of water areas. Trans. 6th N. Amer. Wildlife Conf., 189–198.
(9) **Leedy, D. L.** 1939. Some land-use factors related to pheasant production. Trans. 4th N. Amer. Wildlife Conf., 525–533.
(10) ———. 1940. Fencerows in relation to pheasant production. Mimeo. Release No. 126, Ohio Coop. Wildlife Res. Unit, pp. 1–10.
(11) ———. 1947. A 1947 State-wide game survey. Ohio Conservation Bulletin 11 (12): 14–15.
(12) **Leedy, D. L.,** and **E. H. Dustman.** 1947. The pheasant decline and land-use trends, 1941–1946. Trans. 12th N. Amer. Wildlife Conf., 479–490.
(13) **Ray, G. S., O. M. Frost** and **P. P. Wallrabenstein.** 1943. Ohio Agricultural statistics, 1940, 1941. Ohio Agr. Expt. Sta. in coop. with U. S. Dept. Agr. Bull. No. 642.
(14) **Ray, G. S., A. R. Kendall** and **H. M. Clevenger.** 1946. Ohio Agricultural statistics. Mimeo. bulletin, Ohio Agr. Expt. Sta., May, 1946. In coop. with U. S. Dept. Agr.
(15) **Sitterley, J. H.** 1944. Some factors affecting the ratio of retirement of farms in the submarginal land area in Ohio. Journ. of Farm Economics, 26: 737–753.
(16) **Sitterley, J. H.,** and **J. I. Falconer.** 1938. Better land utilization in Ohio. Dept. of Rural Ec., Ohio State Univ., Mimeo. Bull. No. 108.

Elementary Geography

Geography Around the Home is the name of a taxt for the youngest readers. Its aim is to give children an understanding of the involved transportation, agriculture, industry, and commerce surrounding the commonest acts of every day life. That the book can accomplish so much in its circumscribed space is due to the skill of its authors who know how to omit without offensive over-simplification. In the absence of maps, graphs, or tables of statistics, necessary tools for the higher levels, it aims to prevent a large array of the fundamentals of community living and interregional dependence. One author is Professor of Geography at Miami University, the other a gifted story teller and editor. The reviewer's interest was captured by the problem of how early human ecology can be introduced in the learning process. Carefully selected photographs and drawings by Helen John make a useful and pleasing book.—*A. E. Waller.*

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STAIN COMBINATIONS IN LIVING INSECTS

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The commonly practiced method in stain technique on non-living material is the use of two types of stains. This proves valuable for differentiation of portions of the tissue, for example, setting off the nucleus of the cell from the remainder of the protoplasmic material, as well as other portions of cellular structure. From past experience standards have been set up whereby certain stains are suggested for certain cellular structures or tissues. In the test series discussed in this paper the two general factors taken into account (besides the choosing of stains previously found good for viable tissue) were the acidity or basidity of the stain materials and the coloration, either of a red type or of a blue type.

The present paper is an expansion of the method developed by the author (1946[1]) for differentiating organs and tissues by injection of dilute stains in living animals. In the present experimental series two stains instead of one were used. The series was selected so that in each combination of two stains, one would be of a shade of red and one blue and at the same time one would be acidic in composition and one would be basic. Curiosity was the factor which prompted the author to use red-blue, acidic-basic mixtures of stains to see what shades of color might be obtained upon gross examination of the body organs and tissues and what dominance of one shade over another would appear in such a mixing process. Each individual staining solution was not tested to determine its relative acidity or basidity, but was used from its general classification as an acid or base material. Normal saline (0.85% aqueous solution of sodium chloride) was used as the medium for all the materials.

The materials used were those previously found useful as vital stains with definite color properties and not seemingly too injurious to the insect tissues. Twelve stain materials (dry) were chosen, made into solutions individually with normal saline as the medium, and mixed immediately before injection into the insect. Some difficulty was encountered in the beginning of the work due to the chemical activity of some materials upon mixture; some, allowed to stand for as much as five or ten minutes, would form a thickened or congealed solution which proved difficult to inject as well as toxic to the experimental animals. For this reason the practice of mixing the stain solutions just before injection by the hypodermic needle was used, and, except in four cases, no further serious difficulty was encountered.

The stains used are listed below, followed by their acidic or basic classification:

Bordeaux Red (acidic).	Blue de Lyon O (basic).
Rose Bengal (acidic).	Brilliant Cresyl Blue (basic).
Biebrich Scarlet (acidic).	Azur II (basic).
Congo Red (acidic).	Toluidin Blue (basic).
Safranine O (basic).	Aniline Blue (acidic).
Fuchsin Basic (basic).	Trypan Blue (acidic).

[1]Research work done with the guidance of Dr. C. H. Kennedy, of the Department of Entomology, Ohio State University.

These were used to make twenty combinations (by twos):

Bordeaux Red x Blue de Lyon O.
Rose Bengal x Brilliant Cresyl Blue.
Biebrich Scarlet x Azur II.
Congo Red x Toluidin Blue.
Aniline Blue x Safranine O.
Trypan Blue x Fuchsin Basic.
Bordeaux Red x Brilliant Cresyl Blue.
Bordeaux Red x Azur II.
Bordeaux Red x Toluidin Blue.
Rose Bengal x Blue de Lyon O.
Rose Bengal x Azur II.
Rose Bengal x Toluidin Blue.
Biebrich Scarlet x Blue de Lyon O.
Biebrich Scarlet x Brilliant Cresyl Blue.
Biebrich Scarlet x Toluidin Blue.
Congo Red x Blue de Lyon O.
Congo Red x Brilliant Cresyl Blue.
Congo Red x Azur II.
Aniline Blue x Fuchsin Basic.
Trypan Blue x Safranine O.

Each stain material was weighed and combined with normal salt solution at the rate of 1 gram dry material to 100 cc. normal saline. A small amount of each staining solution used in a combination was mixed with a similar amount of the other material used and the injections of .1 cc. were taken from this mixture. An experimental attempt to inject each stain solution separately proved destructive to the experimental insects both from the puncturing of the body wall by the hypodermic needle and the excessive amount of material introduced into the body cavity.

The experimental insect used in all the work was the American cockroach (*Periplaneta americana*). Under six months of age, the roaches do not prove to be good experimental subjects, consequently only those over six months or fully mature adults were used. These were taken from laboratory cultures where the age could be determined to a close degree.

After the solutions were made from the dry materials seven of them (Brilliant Cresyl Blue, Blue de Lyon O, Trypan Blue, Toluidin Blue, Azur II, Aniline Blue and Congo Red) made homogeneous mixtures as discerned by the eye. The last, Congo Red, was rather thick, and upon revolving the container rather large clumps of material were found clinging to the glass walls. Some settling occurred in Safranine O, Biebrich Scarlet and Bordeaux Red, the last only to a slight degree. In the case of Fuchsin Basic and Rose Bengal the solution appeared thin upon standing for a period of time with a large amount of settling in the bottom of the bottle. While all were shaken before use, these last two mentioned required additional agitation to thoroughly mix the solution. Upon examination all these stain solutions appear to be suspensions of greater or lesser degree rather than true dissolved materials. This is especially noted in the cases where settling occurred.

In the combinations made from the stain solutions those containing Congo Red and Toluidin Blue proved to be the most difficult in the attempts to obtain mixtures. Five of them were definitely thick, viscous liquids. These were Congo Red and Toluidin Blue, Bordeaux Red and Toluidin Blue, Biebrich Scarlet and Toluidin Blue, Congo Red and Blue de Lyon O, Congo Red and Brilliant Cresyl Blue. The remainder of the combinations formed more or less free liquid mixtures, although the appearance of granules or small flakes of material appeared in many of them. The ease of mixing and the thickness of the resulting combination may well be a very important factor in the value of the stain combination from the standpoint of mortality as well as coloring of structures.

METHODS

Insects of proper age were chosen from the laboratory cultures, indiscriminately as to sex, and removed to an anesthetizing jar. A piece of cotton or cheesecloth saturated with ethyl ether was placed in the jar, a tight cover placed over the top, and the insects left until rapid movement of the legs had ceased. By this time the insects were usually lying on their backs and producing slight movements with their bodies and legs. This was done only when everything was ready for the

injections to be made because the roaches will recover quickly when they are the recipients of fresh air.

When calmed so that rapid movements of the legs, etc., would not impede the insertion of the hypodermic needle, the insects were taken out of the anesthetizing chamber and .1 cc. of the mixture to be tested was placed in the body cavity by puncturing the thin cuticle at the base of the third abdominal segment, using a 1 cc. hypodermic with a very fine needle. A rather slow release of the solution in the barrel proves best to prevent injury to internal organs.

The insects were then placed in "housing jars" (i. e., small culture jars) to await the time of dissection which was set at one-half hour, one day, and two days from the time of injection. Before dissection ether was again used to stop rapid movement until the legs could be removed and the ventral wall opened and spread apart on a small dissecting tray. Examination took place under a binocular microscope, as well as with the naked eye. The results of the gross examination of the internal structures is recorded for each stain combination.

RESULTS

The stains used had been selected with the view in mind of their good record previously of low mortality. However, some trouble was encountered in the use of four combinations. These were Safranine O and Aniline Blue, Rose Bengal and Toluidin Blue, Congo Red and Blue de Lyon O, Congo Red and Azur II. While no difficulty was apparent at one-half hour intervals, attempts to have survival of injected insects for one and two day periods necessitated many more trials than was the case with any of the others of the series.

Certain expressions used in connection with the descriptions of stain results to identify structures are of common recognition and do not need further explanation while others are those used by the author to clarify differentiated areas. The terms salivary glands, oesophagus, stomach, gizzard, malpighian tubules, tracheae, fat bodies, leg muscles, femurs, ovaries, testes, gastric caecae, ventral nerve cord are ones easily identified in the roach from a previous study of its internal structures or those of many of the other common insects. The terms "dorsal wall material" and "ventral wall material" refer to the fatty tissue lying next to the body wall of the respective surfaces. These quite often appear to be the same color as the fat bodies lying in the abdomen, but in a few cases differ in shade or color. The intestine portion of the digestive tract has been divided into three determinations. The "entire intestine" is used when the same shade is found throughout the entire length of the intestine; "upper intestine" for the upper half (using caudal-anal direction) and "lower intestine" for the lower half (if a smaller area is considered, it is designated as one-third, one-fourth, etc.). The words "heart outline" are used when a color appears to form an outlining band along either side of the heart area. The term "entire heart" includes both the true heart and the dorsal aorta, "true heart" the heart proper, and "dorsal aorta" the portion usually designated as such. "Heart wing muscles" is used for those V-shaped muscles, whose base is toward the heart, extending from the heart outward along the tracheae.

Each of the stain combinations were tested over a period of two days at the most. Dissections and examinations were made at intervals of one-half hour, one day and two days. In the records of this testing, the descriptions have been arranged in such a way that the time interval giving the best results from the standpoint of color variety and the number of structures shown to be affected is given first under the appropriate heading, with the introductory words *Best timing.* In this portion each of the organs and tissues affected are presented with the color noted in the examination. This part is followed by information of the other two time intervals with the structures affected and the colors represented merely listed.

In a review of the various combinations it has been noted that only three out of the twenty used showed a dominance of blue shades, i. e., including blue, violet, etc., more than red, rose, pink, etc. Toluidin Blue was the "blue" stain used in each of these (Congo Red x Toluidin Blue, Bordeaux Red x Toluidin Blue, Biebrich Scarlet x Toluidin Blue). In nine combinations the "red" predominated and in eight the red and blue shades were about equal. It might be noted that two, Safranine O and Aniline Blue, were used only twice each in combination with another stain, and the red shades were dominant in the resulting four sets of the test series. In all the combinations lavender was one of the colors appearing on the affected structures. No other color or shade was found throughout the entire series.

ROSE BENGAL X TOLUIDIN BLUE

Best timing: One day—salivary glands, deep lavender; oesophagus, stomach, gastric caecae, light violet; gizzard, violet; intestine, violet to lavender; malpighian tubules, deep red (wine) or deep purple; heart outline, heavy purple, with outer edge lavender; entire heart, ventral nerve cord, rose; dorsal wall material, rosy-violet or fuchsia; ventral wall material, fuchsia; fat bodies, bright blue with some lavender shading; leg muscles, femurs, lavender; ovaries, rose to lavender.

Half hour—Structures: salivary glands, oesophagus, stomach, gizzard, gastric caecae, intestine, malpighian tubules, entire heart, dorsal and ventral wall material, fat bodies, leg muscles. Colors: violet, lavender, blue.

Two days—Structures: salivary glands, stomach, gizzard, gastric caeace, intestine, malpighian tubules, entire heart, dorsal wall material, fat bodies, leg muscles. Colors: lavender, pink, purple, violet, rose, blue.

ROSE BENGAL X BLUE DE LYON

Best timing: One day—salivary glands, lavender; stomach, gizzard, violet tinge; gastric caecae, light violet; intestine, mostly violet; malpighian tubules, one-half scarlet; entire heart, pink and violet blended (whole looks purple); dorsal wall material, deep violet; fat bodies, one-third violet, rest bright pink; spermatotheca, dark lavender to violet.

Half hour—Structures: salivary glands, oesophagus, stomach, gizzard, gastric caecae, intestine, entire heart, dorsal wall material, fat bodies, leg muscles, testes. Colors: lavender, violet, dark red, scarlet, purple, orange.

Two days—Structures: salivary glands, stomach, gastric caecae, intestine, malpighian tubules, entire heart, dorsal wall material, fat bodies, ventral wall material. Colors: lavender, rose, scarlet.

BORDEAUX RED X TOLUIDIN BLUE

Best timing: Two days—Gizzard, intestine, deep purple; gastric caecae, dark lavender (extended); malpighian tubules, deep wine red; entire heart, deep purple (color flakes present); dorsal wall material, greenish blue; fat bodies, mostly pale blue; leg muscles, femurs, dull green; ovaries, yellow-green; ovarian tubes, light to median blue; ventral nerve cord, blue tinged, darker at ganglia.

Half hour—Structures: salivary glands, gastric caecae, malpighian tubules, entire heart, dorsal wall material, fat bodies. Colors: purple, blue, lavender, rosy-lavender, violet, pink.

One day—Structures: salivary glands, stomach, gastric caeace, upper intestine, malpighian tubules, heart outline, dorsal wall material, fat bodies. Colors: purple, blue, lavender, red, violet.

SAFRANINE O X TRYPAN BLUE

Best timing: Two days—salivary glands, light lavender; gizzard, upper part pink, lower part lavender; gastric caecae, leg muscles, deep rose; intestine, rosy

lavender tinge; malpighian tubules, one-half rose; heart outline, heart wing muscles, violet; entire heart, dark purple; dorsal wall material, salmon (some pink); ventral wall material, lavender; fat bodies, pink; ovaries (and tubes), rosy lavender.

Half hour—Structures: salivary glands, stomach, gizzard, intestine, malpighian tubules, entire heart, dorsal wall material, fat bodies, leg muscles, testes. Colors: lavender, rosy lavender, red, pink, salmon.

One day—Structures: salivary glands, stomach, gastric caecae, upper intestine, entire heart, dorsal wall material, fat bodies. Colors: pink, lavender.

BIEBRICH SCARLET X BRILLIANT CRESYL BLUE

Best timing: Half hour—salivary glands, light violet; stomach, reddish; gizzard, lavender; gastric caecae, slightly reddish; entire heart, heart wing muscles, dark purple; dorsal wall material, bright pink to lavender; fat bodies, pink, lavender and violet; leg muscles, bright pink streaks; testes, pale to bright blue.

One day—Structures: salivary glands, malpighian tubules, entire heart and outline, dorsal wall material, fat bodies, leg muscles, ovaries. Colors: pink, dark red, brown, orange, blue, lavender.

Two days—Structures: salivary glands, gizzard, gastric caecae, upper intestine, malpighian tubules, entire heart, dorsal wall material, fat bodies. Colors: lavender, pink, red, brown, blue, salmon.

CONGO RED X TOLUIDIN BLUE

Best timing: Two days—salivary glands, faint blue tinge; stomach, lower one-third light lavender; gizzard, lavender; gastric caecae, faint lavender tinge at base; intestine, deep lavender with some light purple portions; malpighian tubules, lavender (granular appearance); heart outline, heavy dark purple with heavy violet accumulation along edge; heart wing muscles, purple to violet; dorsal wall material, very bright blue, some bright violet immediately along tracheae; ventral wall material, yellowish blue; fat bodies, mostly pale to bright blue in abdomen, few light violet spots. Presence of dark purple flakes noted in center of body.

Half hour—Structures: gastric caecae, intestine, fat bodies, testes. Colors: lavender, purple, blue, red.

One day—Structures: salivary glands, stomach, gizzard, gastric caecae, intestine, heart outline, dorsal and ventral wall material, fat bodies. Colors: blue, lavender, violet, black.

BIEBRICH SCARLET X BLUE DE LYON

Best timing: One day—salivary glands, stomach, lavender; gizzard, gastric caecae, leg muscles, light lavender; upper intestine, deep lavender (almost purple); malpighian tubules, orange-red; entire heart, deep blue; dorsal wall material, lavender tinges; ventral wall material, mostly deep blue.

Half-hour—Structures: salivary glands, stomach, gastric caecae, dorsal aorta, dorsal wall material. Colors: lavender, orange, pink.

Two days—Structures: stomach, intestine, malpighian tubules, entire heart, dorsal wall material, fat bodies. Colors: blue, lavender, orange-red, pink.

FUCHSIN BASIC X TRYPAN BLUE

Best timing: Two days—salivary glands, lavender; gizzard, bluish tinge; gastric caecae, lavender tinge; malpighian tubules, lavender to scarlet (granular); dorsal aorta, femurs, purple; heart wing muscles, purple; fat bodies, faint blue tinge in thorax, some lavender tinge in abdomen; leg muscles, deep blue.

Half-hour—Structures: salivary glands, stomach, malpighian tubules, dorsal aorta, testes. Colors: lavender, rosy lavender, pink, scarlet.

One day—Structures: salivary glands, gizzard, gastric caecae, malpighian tubules, dorsal aorta, dorsal wall material, leg muscles, ovaries. Colors: lavender, blue, scarlet.

BORDEAUX RED X BRILLIANT CRESYL BLUE

Best timing: Half hour—salivary glands, deep bright blue; gizzard, lavender tinge; gastric caecae, purple tinge (enlarged); malpighian tubules, dull wine red; entire heart, red tinge; heart wing muscles, deep purple with spot of orange-red in center; fat bodies, in abdomen ventral side pink to deep lavender, dorsal side pink, bright pink and lavender; leg muscles, deep blue; oviducts, light blue.

One-day—Structures: salivary glands, gastric caecae, upper intestine, malpighian tubules, heart outline, dorsal wall material, fat bodies. Colors: pink, scarlet, red, violet, purple, lavender, blue.

Two days—Structures: malpighian tubules, heart outline. Colors: red, lavender.

ROSE BENGAL X AZUR II

Best timing: Half hour—salivary glands, lavender; stomach, partially violet; gastric caecae, dark orange; intestine, orange; malpighian tubules, rose and orange; entire heart, purple; heart wing muscles, light purple; dorsal wall material, rose-pink to lavender; fat bodies, bright rose (almost scarlet) to violet.

One day—Structures: salivary glands, gizzard, gastric caecae, upper intestine, malpighian tubules, entire heart, dorsal wall material, fat bodies, ovaries. Colors: lavender, pink, rose.

Two days—Structures: gizzard, gastric caecae, intestine, malpighian tubules. Colors: blue, rose, violet.

CONGO RED X BLUE DE LYON

Best timing: Half hour—salivary glands, lavender; stomach, gizzard, intestine, gastric caecae, dark red-brown; entire heart, heart wing muscles, maroon; dorsal wall material, dark purple; fat bodies, pink or lavender tinged; testes, dull pink.

One day—Structures: salivary glands, stomach, malpighian tubules, entire heart, dorsal wall material, fat bodies, gastric caecae. Colors: lavender, rust (orange-brown), salmon, orange. General appearance is salmon.

Two days—Structures: salivary glands, stomach, gizzard, intestine, malpighian tubules, heart outline, fat bodies, gastric caecae. Colors: lavender, blue.

SAFRANINE O X ANILINE BLUE

Best timing: One day—salivary glands, lavender (with bright orange "veins"); gastric caecae, bright rose; intestine, one-half rosy lavender; malpighian tubules, bright orange-red; entire heart, lavender tinge; heart wing muscles, light lavender; dorsal wall material, salmon to median orange; fat bodies, salmon; leg muscles, deep pink; ovarian tubules, partially blue; nerve cord ganglia, pink tinge. Overall appearance is salmon.

Half hour—Structures: salivary glands, stomach, gastric caecae, malpighian tubules, dorsal wall material, fat bodies. Colors: pink, orange.

Two days—Structures: stomach, gastric caecae, intestine, dorsal and ventral wall material. Colors: bluish-green, orange-red, pink, lavender, rose.

FUCHSIN BASIC X ANILINE BLUE

Best timing: Two days—salivary glands, very light blue; stomach, spots of blue and lavender; gizzard, gastric caecae, medium blue; intestine, dark lavender to purple or blue; malpighian tubules, light purple or fuchsia (with minute dark granules); entire heart, dorsal wall material (mostly), testes, light blue; heart wing muscles, very light blue.

Half hour—Structures: salivary glands, stomach, gizzard, gastric caecae, malpighian tubules, entire heart, dorsal wall material. Colors: blue, lavender, orange-brown, pink, rose.

One day—Structures: salivary glands, gizzard, lower intestine, malpighian tubules, entire heart, dorsal wall material, femurs. Colors: blue, lavender, scarlet.

BIEBRICH SCARLET X TOLUIDIN BLUE

Best timing: One day—salivary glands, very dark lavender; stomach, lower one-half light purple; gizzard, lavender; gastric caecae, tips violet; intestine, small portion blue with rest lavender; malpighian tubules, uncolored or with some portions deep wine red; heart outline, violet; heart wing muscles, heavy violet; dorsal wall material, mostly light blue; fat bodies, creamy, pale, medium or dark blue or violet. Globules of dark blue material through body.

Half hour—Structures: salivary glands, stomach, gizzard, intestine, entire heart, dorsal wall material, fat bodies, leg muscles. Colors: violet, purple, blue.

Two days—Structures: gizzard, gastric caecae, intestine, malpighian tubules, heart outline, dorsal wall material, fat bodies. Colors: lavender, purple, blue, violet.

ROSE BENGAL X BRILLIANT CRESYL BLUE

Best timing: Half hour—salivary glands, deep rose-lavender; gastric caecae, slight pink tinge; malpighian tubules, pale to light, bright blue; dorsal aorta, anterior one-fourth rose, remainder deep lavender; dorsal wall material, rose lavender; fat bodies, posterior one-third (abdomen) pink, rest deep rose and lavender combination; leg muscles, light blue tending to lavender; femurs, scarlet.

One day—Structures: gizzard, gastric caecae, intestine, malpighian tubules, entire heart, fat bodies. Colors: lavender, red, light blue, rose.

Two days—Structures: gastric caecae, upper intestine, heart outline, dorsal wall material, fat bodies. Colors: red, pink, brown, blue.

BORDEAUX RED X BLUE DE LYON

Best timing: One day—salivary glands, lavender (with blue "veins"); stomach, fat bodies, dark blue streaked; intestine, traces of light violet; malpighian tubules, light rosy lavender; heart outline, heavy blue coloring at entrances of tracheae (granules present); dorsal wall material, some pale lavender tinges with some scattered blue spots; ovaries, deep lavender with few blue spots.

Half hour—Structures: salivary glands, lower intestine, malpighian tubules, heart outline and entire heart, fat bodies. Colors: lavender (pale and reddish), blue, red, scarlet.

Two days—Structures: gastric caecae, malpighian tubules, heart outline, fat bodies, ovaries. Colors: blue, scarlet, dull red, lavender.

BORDEAUX RED X AZUR II

Best timing: One day—gastric caecae, light green tinge; intestine, mostly purple; malpighian tubules, one-half very faint pink; heart outline, brown pigmented; dorsal aorta, orange-pink; heart wing muscles, light tan; fat bodies, tinges of light blue and light pink.

Half hour—Structures: salivary glands, stomach, malpighian tubules, entire heart, dorsal wall material, testes. Colors: lavender, pink, red, blue.

Two days—Structures: gastric caecae, malpighian tubules, intestine. Colors: red, bright yellow, violet, lavender.

CONGO RED X AZUR II

Best timing: Two days—gastric caecae, upper intestine, faint pink; heart outline, dark brown (flaky material); heart wing muscles, light orange-brown; dorsal wall material, salmon (scattered spots between tracheae); ovaries, few orange spots. Clumps and flakes of very dark reddish brown material through body cavity.

Half hour—Structures: salivary glands, entire heart. Colors: pink, yellowish brown. Brown flakes scattered through body.

One day—Structures: salivary glands, upper intestine, entire heart, dorsal and ventral wall material, fat bodies, leg muscles. Colors: blue, lavender, violet, rosy

lavender. Dark violet (crystalline) material found in spots on dorsal side of fat material.

CONGO RED X BRILLIANT CRESYL BLUE

Best timing: One day—salivary glands, pale lavender; heart outline, heavy brown pigment; dorsal aorta, some orange (deeper than normal); heart wing muscles, orange-brown (brown specks present); dorsal wall material, salmon; oesophagus, stomach, gizzard, gastric caecae, intestine, orange. Impression of body cavity taken as a whole is of a salmon color; this is especially true to the naked eye.

Half hour—Structures: salivary glands, entire heart, dorsal wall material, fat bodies. Colors: lavender, violet, red, pink. Dark brown flecks through body cavity.

Two days—Structures: salivary glands, gastric caecae, intestine, malpighian tubules, entire heart, dorsal wall material, fat bodies. Colors: pink, orange-red, red, orange, orange-yellow. Brown pigment through body cavity. Body cavity as a whole looks orange.

BIEBRICH SCARLET X AZUR II

Best timing: Half hour—salivary glands, light, bright blue; malpighian tubules, few posterior ones light blue, few dull red (with minute red granules); heart wing muscles, purple; fat bodies, portions of pink and blue (light); leg muscles, pale blue; testes, light blue.

One day—Structures: stomach, intestine, malpighian tubules, testes. Colors: lavender, deep red, rose.

Two days—Structures: gastric caecae, intestine, malpighian tubules, heart outline. Colors: purple, violet.

REFERENCES

Bensley, Robert R. 1938. *Handbook of Histological and Cytological Technique.* Univ. of Chicago Press, Chicago, Ill.

Conn, H. J. 1940. *Biological Stains.* 4th ed. Biotech Publications, Geneva, N. Y.

Hershberger, R. V. "Differential Stains of Insect Tissues." Ohio Jour. Sci., 46: 152–162 May, 1946.

History of the Grasslands of North America

These two books which must be read together to form a fair appraisal of the author's intention, present the first really important bibliography of the natural conditions of the central region of the United States. In preparing his manuscripts some 2500 titles of primary sources have been carefully reviewed. The ecologists as well as the geographers and agronomists will find a wealth of background material which cannot be overlooked any longer as exploration and exploitation give way to the responsibility of dealing with an environment which contrasts so markedly from the eastern forested land areas. The author's concept of the grassland formations is strikingly like that of the early competent description and emphasizes the same plant types made familiar in the writings and lectures of John H. Schaffner. The second part of the work owes its inspiration in great part to the publication of N. S. Shaler. The total impression left with the reader is a more complete and more reliable account than found in some of the modern ecologists' efforts. What makes Malin's work valuable to an understanding of the social implications of the grassland is the main thesis that social process is rooted to the environment. Only exceptional histories have revealed awareness of this relation.

It is unfortunate for the distribution of these books that a publisher who would bring the work to the attention of a large reading public was not selected. The books must be obtained directly from the author.—*A. E. Waller.*

(1) The Grassland of North America. (Prolegomena to its history), 1947.

(2) Essays on Historigraphy, 1946. Published by James C. Malin, 1541 University Drive, Lawrence, Kansas.